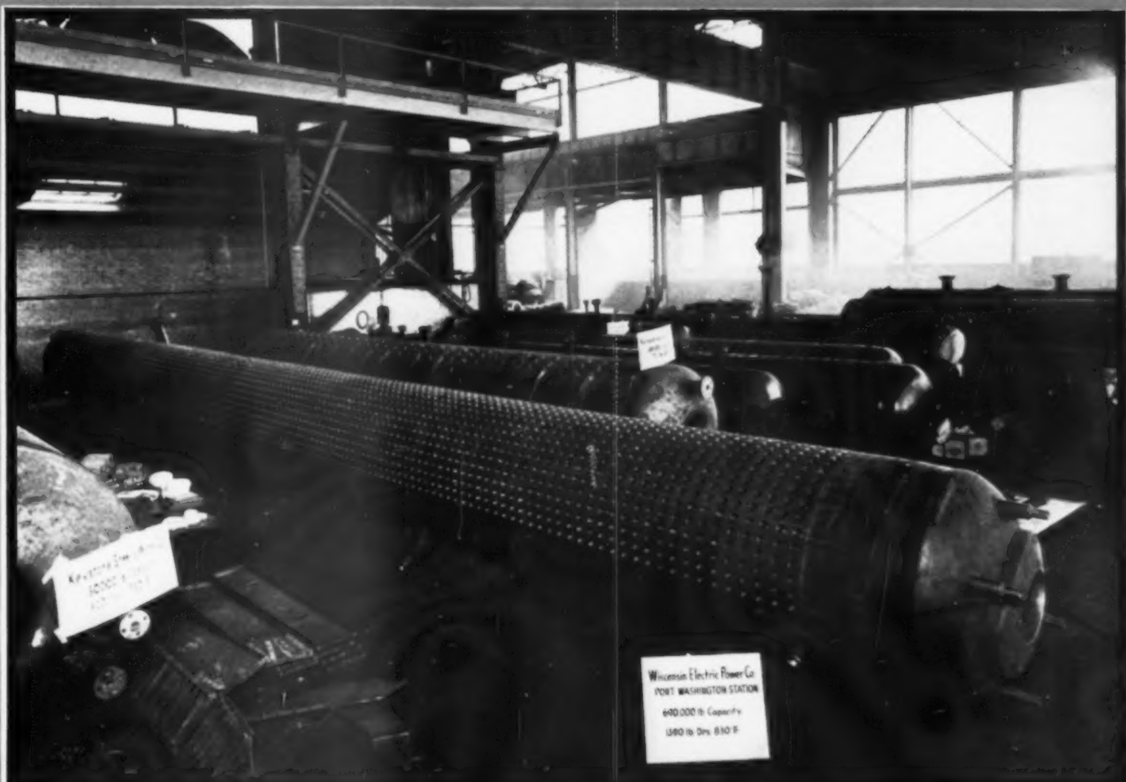
COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

June, 1946

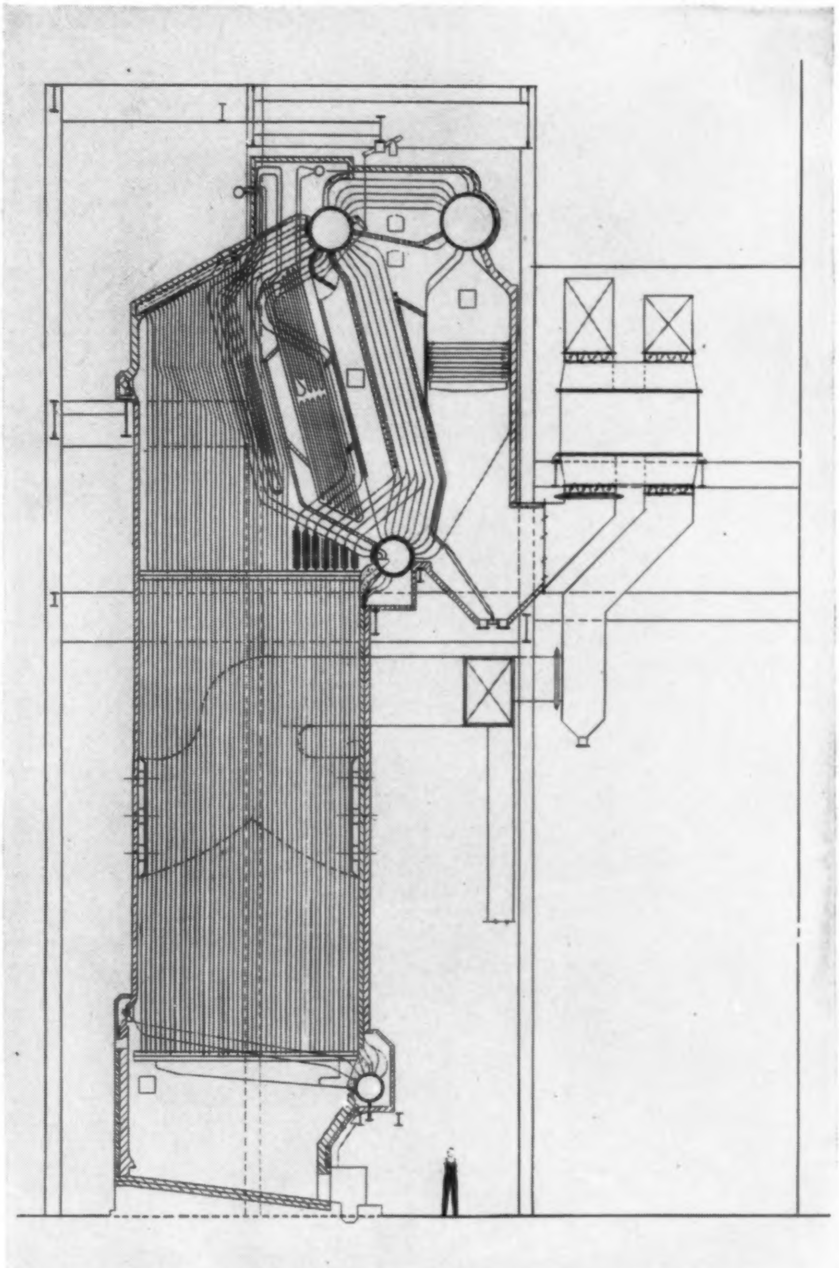


Drums awaiting shipment. That in foreground is over 61 ft long, 40 in. inside diameter and 5¼ in. thick. It is for the latest 690,000-lb. per hr, 1390-psi unit at Port Washington

Magnetic Drive for Adjustable-Speed, Torque Transmission

Instrumentation for Study of Furnace Performance

The Products of Corrosion



COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

VOLUME 17 **NUMBER 11**

Contents

JUNE 1946

Feature Articles

Editorial

Departments

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Editorial

Henry Kreisinger

Shortly before the May issue went to press, word was received of the death of Henry Kreisinger. There was time only for an obituary notice. However, because of his outstanding contributions to the art of fuel burning, his prestige as an authority on fuels and his personal attributes, further comment seems in order.

Henry Kreisinger personified American opportunity. Coming to this country alone from Bohemia as a poor boy of fifteen, without knowledge of our language, but with a firm determination to acquire a technical education, he worked for eight or nine years in various machine shops gaining practical experience and devoting all his spare time to study. By 1900 he had saved enough to begin a long-cherished college education and entered the University of Illinois. There he studied under the late Professor Breckinridge to whom he often attributed much credit for subsequent success. He graduated in 1904 with the degree of B.S. and two years later he received the M.E. degree.

At about this time the U. S. Geological Survey was embarking on its exhaustive program of fuel testing at St. Louis and Pittsburgh, and Kreisinger, by becoming associated with this work, charted his future. His subsequent work with the U. S. Bureau of Mines is well known by the numerous reports of which he was author or co-author, and which still serve as basic references.

In 1920, when Mr. Kreisinger joined Combustion Engineering Company, the burning of coal in pulverized form under stationary boilers was in its infancy. He set about applying his fundamental knowledge and technique to overcoming the many problems with this type of firing, particularly its application to large steam-generating units, and the ultimate success was in no small measure due to his efforts. In later years, as Director of Research, his work encompassed a wide range of research projects in the field of fuel burning and steam generation.

Those who, over the years, were privileged to listen to the presentation of Mr. Kreisinger's many papers before the A.S.M.E. and other engineering societies, will recall his logical reasoning and clarity of expression. In a broad sense, he was a teacher who sought always for simplicity of exposition and achieved it to a reasonable degree. In fact, simplicity was the keynote of his character and was manifest in everything he said and did. He will also be remembered by his many friends for his invariable forthrightness and honesty of opinion.

In both achievement and character Henry Kreisinger deserves to be ranked among the great engineers of his time.

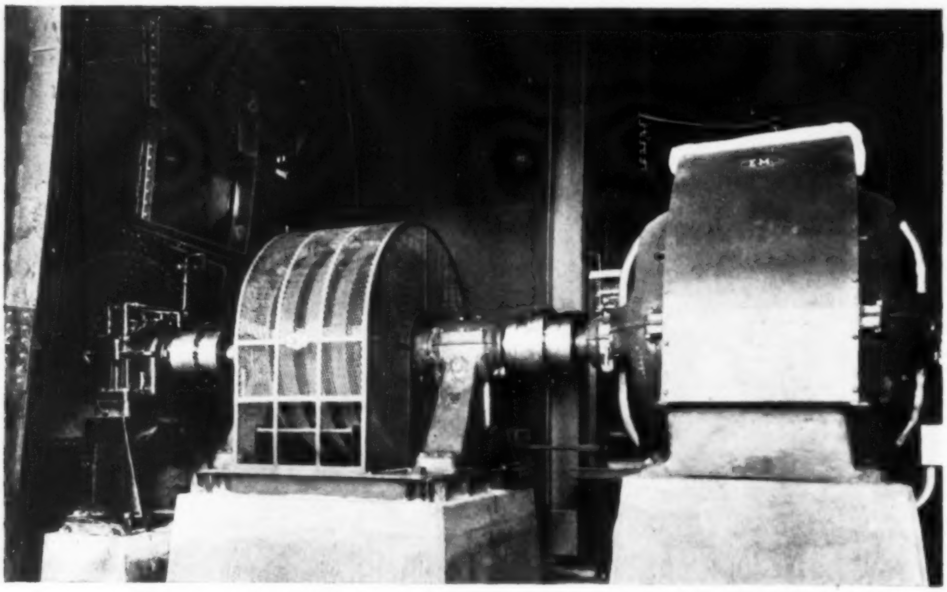

Fig. 1—This 752-hp, 1164/180-rpm magnetic drive operated by a synchronous motor is one of three units on induced-draft fans at a large southern power company's plant.

MAGNETIC DRIVE for Adjustable-Speed Torque Transmission

By GLENN STANGLAND

Elec. Engr., Electric Machinery Mfg. Co.,

The power industry has extensive application for automatically controllable torque transmission through a wide range of speed. The magnetic drive is the logical choice for those applications with a horsepower-torque relationship such as that found with boiler draft fans. This article deals with the construction, operation and general characteristics with respect to application of the adjustable speed magnetic drive.

THE adjustable-speed magnetic-drive system consists essentially of a constant speed motor driving a ring. Rotating within the ring is a magnet, coupled to the fan shaft or other load. Operating speed of the magnet is controlled by adjusting the direct current excitation to the magnet poles by means of an automatic electronic controller which uses a simple potentiometer pickup from the primary sensing device. Fig. 2 represents one form of drive using the "cage-current" ring applied to the larger horsepower sizes, and Fig. 3 shows the construction of the cage-current ring. Figs. 4 and 5 are of the "eddy-current" form of construction for smaller capacities, and Fig. 6 shows the magnet construction.

The combination is readily recognized as an adaptation of a squirrel cage motor in which both the rotor and the frame are allowed to rotate, but at variable relative speeds. Cage bars in the ring are similar to squirrel-cage motor construction, and rotation of the magnet energized from the control produces a revolving field such as the primary field developed in a squirrel-cage induction motor. In the eddy-current form, the principle of operation is the same, but currents in the magnet do not have the directed low-resistance circulation provided by squirrel-cage bars in the cage-current type. The difference is a matter of capacity, and the eddy-current construction is generally used in the smaller ratings. The only wearing parts of the drive are the bearings and collector rings, there being no mechanical torque connection between ring and magnet. Control is achieved electrically by varying the direct current through the magnet to transmit torque through the air gap.

Operation

The ring of the magnetic drive revolves at the same speed as the driving motor. The magnet, separated by an air gap from the ring, is free to revolve within the ring. Poles of the magnet are excited by direct current through collector rings on the magnet shaft. The magnet is of salient-pole construction, so connected as to produce alternate north and south poles.

A difference in speed between the ring and the magnet results in a cutting, by the ring, of the magnetic flux produced by the magnet. This induces current in the

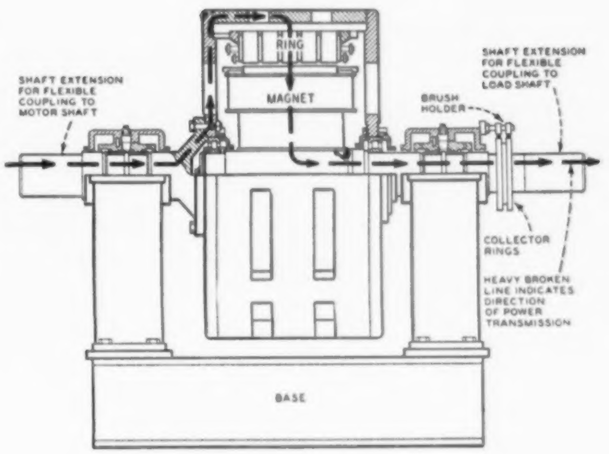

Fig. 2—Diagrammatic cross-section of E-M magnetic drive for larger powers showing constructional elements.

ring, forming a magnetic field in the air gap. The magnetic field pulls on the poles of the magnet, thereby causing the latter to revolve. Torque transmission takes place through the air gap. The amount of torque is varied precisely and over a wide range by varying the excitation of the magnet, thus controlling its speed. The speed of the magnet is dependent at any time on two factors: (1) the amount of control current, which determines the torque transmitted between motor and load, and (2) on the torque required by the load. Since the amount of control current is instantly controllable electronically, the load speed can be kept constant regardless of change.

The difference in speed between ring and magnet can be considered in terms of slip. When the magnet is stationary and the ring is at full motor speed, the slip is 100 per cent; but as the speed of the magnet increases, the slip decreases proportionally to the speed. When full rated excitation is applied to the magnet, and it is carrying full rated load, the slip is 3 per cent, which is the standard rated, full-load minimum slip; thus, the maximum load speed is 97 per cent of the speed of the motor. It is apparent that the treatment of the magnetic drive as a "slip" device is exactly the same as that for a multiphase squirrel-cage induction motor.

The magnetic drive is purely a torque transmitter; its torque output is always approximately equal to the torque input at any speed. It is not a torque converter (multiplier).

Characteristics

Speed Response.—A change in excitation to the magnetic drive causes a practically instantaneous change in the torque transmitted. The rate of change of speed of the load, however, depends not only on the change of torque, but on the WK^2 of the load as well. The available maximum torque for acceleration will generally be not less than full load torque at the usual range of load operation.

Losses.—The losses consist of slip loss, which appears as heat loss in the ring; excitation loss in the magnet; windage and friction loss. The slip loss is the principal loss, the latter two being quite small. The slip loss varies directly with the difference in speed of rotation between ring and magnet, or between motor and load. Thus, at 3 per cent minimum slip, 3 per cent of the output of the motor will be dissipated as slip loss in the ring.

In the most important application, that of boiler draft fans, the power requirement drops off rapidly at reduced speed. With the fan shaft operating at 50 per cent of the motor speed, 50 per cent of the output of the motor at that fan speed will be slip loss in the ring. At such reduced speed, the energy dissipated in the magnetic drive is not unduly large because the power required by the fan decreases approximately at the cube of its speed. Motor power output is consequently reduced to a com-

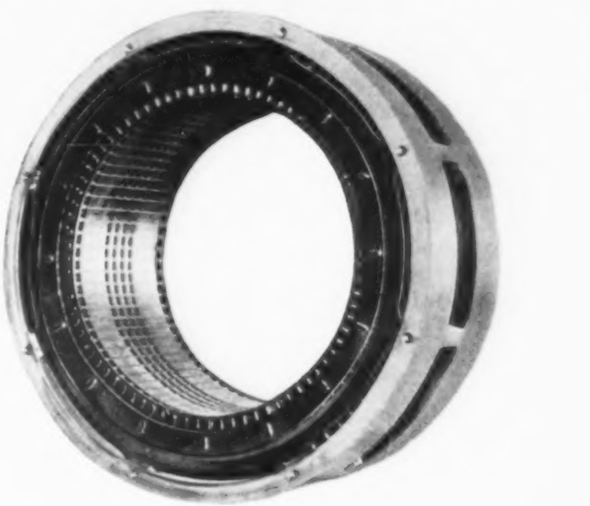

Fig. 3—Ring with laminated core and a specially designed cage winding, similar to that of an induction motor.

paratively small value. The magnetic drive slip loss at its maximum is only 15 per cent of the full-load rating of the magnetic drive when operating a fan or load of similar characteristics.

Fig. 7 shows the horsepower and loss relationship in a magnetic drive connected to a fan.

The slip loss characteristic of the magnetic drive is inherent in all torque transmitters operating on a slip

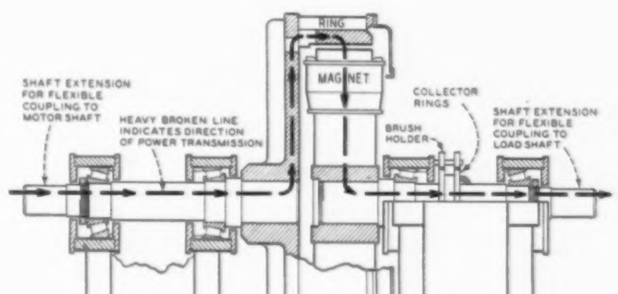

Fig. 4—Diagrammatic cross-section of E-M magnetic drive for smaller capacities. Each pedestal contains two ball (or roller) bearings, supporting the over-hung ring and magnet and maintaining them in axial alignment.

Fig. 5—Ring of "eddy-torque" type, consisting of a specially built annealed steel ring with radiating fins.

principle. It occurs with a slip-ring induction motor when the speed is reduced by inserting resistance in the rotor circuit, and the loss is dissipated in a bank of resistors separate from the motor.

No external cooling devices are used. The ring revolves always at motor speed, which makes it practical to self-cool the ring effectively. The magnet may operate a low speed, but the somewhat less effective self-ventilation is fully compensated for by the low excitation current that is then required. Thus, inherently the operation and construction of the magnetic drive are favorable for effective heat dissipation.

Stability.—By adjusting the value of control current, any desired per cent of torque transmission, and consequently of load speed, may be obtained. In the electronic control used, the control current is referred to the load speed; the control maintains constant speed regardless of load. Properly timed response of the electronic control as compared with time characteristics of the drive and load, as well as control circuit design to eliminate electrical "slack," prohibits hunting or erratic operation of the magnetic drive. The use of rugged pickup equipment from the primary sensing device and moderate amounts of control power without trick circuits eliminates "phantom" malfunctions which may occur in high-amplification electronic circuits when control current leakage results from the entrance of small amounts of moisture into the wiring.

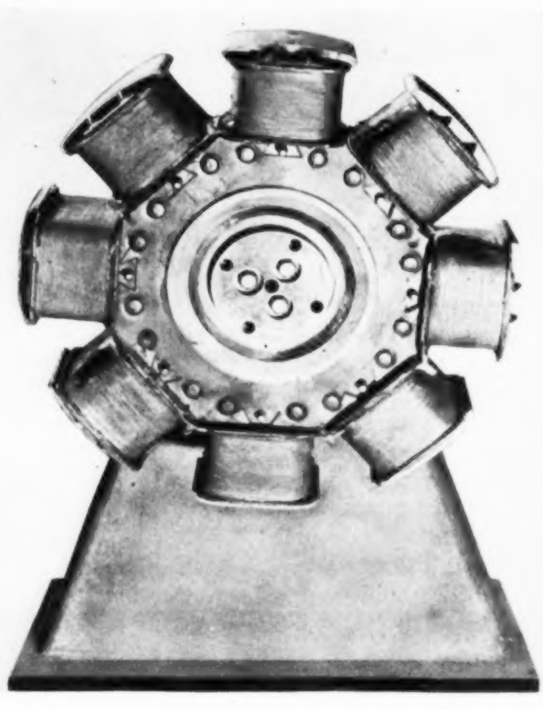

Fig. 6—Magnet of salient-pole construction.

Control

Control of excitation to the magnet and thus of the speed is accomplished electronically. A three-phase, 220- or 440-volt supply is rectified and controlled to maintain the adjustable speed requirements.

Output of a small tachometer generator driven from

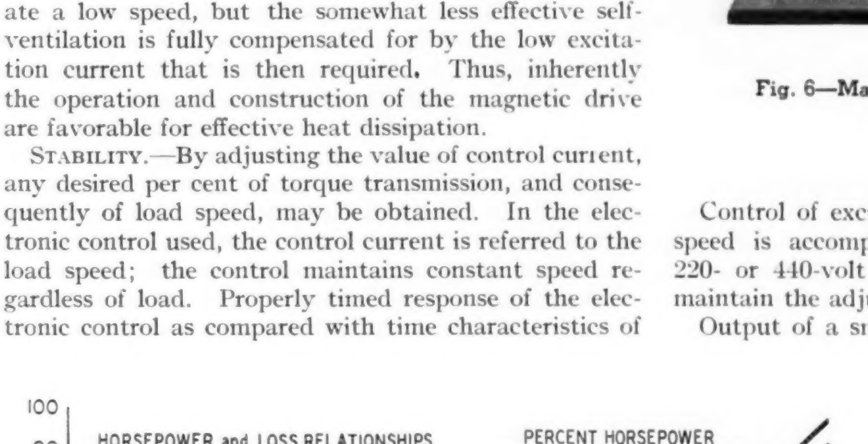

Fig. 7.—Horsepower dissipated in the magnetic drive in reducing speed of the fan is shown by the typical "wha'e-back" Curve C. Horsepower from Curve C, added to actual power required to drive the fan at any given speed on Curve B, gives the total horsepower input to the driving motor, Curve A.

the magnet shaft actuates the control to hold operating speed of the load accurately as selected. Speed is selected by positioning the arm of a small potentiometer which is actuated by some type of automatic control such as the usual form of automatic combustion control.

The speed level is adjusted by the automatic control, and since changes in speed are referred to a tachometer, the selected speed is maintained under conditions of variations in prime mover speed or changes in load or voltage.

Vacuum tubes used in the control are standard types loaded at a conservative fraction of normal rating, with a normal life expectancy of 10,000 to 20,000 hr. The amplifier tubes are high vacuum types, and the power tubes furnishing magnet excitation are gas filled. They can be replaced while the control is in use.

Stability in the control circuit is achieved by providing the control circuits with current and voltage-stabilizing transformers which are sensitive to rate of change of excitation current to the magnet and tachometer pickup voltage. The values obtained from these transformers are used to oppose rapid control current changes, thereby reducing magnetic drive acceleration and preventing load-speed "overshoot," and hunting. Their effects are absent under steady-state conditions since one carries direct current from the tachometer and the other carries direct current from the magnet; there is no transformer action under steady-state operation of the magnetic drive.

The only rapidly moving part of the control is the tachometer belted to the magnet shaft.

Application Considerations

Inherent features of the drive are advantageous in any application characterized by load torque which drops off rapidly with speed reduction; fans, centrifugal pumps, centrifugal refrigeration compressors, and centrifugal blowers fall in this classification. Magnetic drives are used for cement kiln fans, iron ore sintering fans, wind tunnels, propeller test stands, and other applications where the flow of air must be regulated, or known. The largest field is boiler draft fan, forced or induced. For such use, the magnetic drive has low losses through the range of operating speeds, and is a low-fixed-cost item.

Convenience Plus Accuracy in Heat Balance Computations

BY A. H. ZERBAN

State College, Pa.

FOR a number of years it has been common practice, when figuring a boiler test heat balance, to calculate the item relating to heat loss due to evaporating and superheating the moisture in coal, and that due to moisture formed from the combustion of hydrogen, by an expression similar to this:

$$Q = W(1090.7 + 0.455\ t_g - t_f),$$

where W = weight of moisture per pound of fuel, t_g = temperature of the flue gas, in deg F, and t_f = temperature of the fuel supplied.

This formula, with slight changes in the constants employed, appears in most textbooks on this subject, and has long been accepted with the reservation that it is an approximation. As an approximation, it would be justified if no other convenient means were available, but since the advent of modern steam tables, its use is not only obsolete but unnecessary.

A shorter, and at the same time more accurate method, is to use the expression:

$$Q = W(h - h_f),$$

where h = enthalpy of superheated steam at the flue-gas temperature and under an absolute pressure of 1 lb per sq in., and h_f = enthalpy of the liquid at the temperature of the fuel supplied to the furnace. For example, to determine the heat lost per pound of moisture if the flue gas is at 600 F and the coal is supplied at 80 F, from superheated steam tables at 1 lb per sq in. absolute pressure and 600 F, read h = 1335.7, and subtract h_f at 80 F (= 48), obtaining a difference of 1287.7 Btu per pound of moisture.

For convenience and speed, the above example is obvious; for proving its accuracy, a brief analysis of the thermodynamics of low-pressure superheated steam properties is in order.

It is a fact that the moisture in stack gases exists at its partial pressure, in accordance with Dalton's Law of Partial Pressures. This partial pressure of superheated steam in stack gases will be in the vicinity of 1 to 2 lb per sq in. absolute, depending upon the moisture in the fuel and upon its hydrogen content, and to a slight extent upon the humidity in the air supplied for combustion. However, a glance at the superheated steam tables for enthalpies at 1 and 2 lb per sq in. absolute pressures shows that h is unaffected by slight changes in pressure and is practically a function of temperature only. This is further shown by a Mollier Diagram on which the temperature lines for the region under discussion become horizontal, parallel with enthalpy lines.

As a further justification for the use of this convenient method, let it be recalled that over a wide temperature range, the use of steam tables is far more accurate than that of an approximate formula using constant specific heats.

An extension of this method to calculate the heat loss due to humidity in the air supplied to the furnace can be accomplished by using the same h for the flue-gas temperature determined above, and subtracting from it the h of the vapor at the temperature of the air supplied. Where low-temperature superheated vapor properties are not directly available, h_g from the saturated steam tables may be used with good accuracy. This likewise has an excellent application in humidity calculations for air-conditioning work.

Instrumentation For The Study Of Furnace Performance

By A. R. MUMFORD

Combustion Engineering Company

The following is from a report presented at the 37th Annual Meeting of the National District Heating Association, June 3 to 6, at Virginia Beach, Va. It discusses one phase of the work now being carried out by the A.S.M.E. Research Committee on Furnace Performance Factors, with particular reference to measurement of furnace-tube surface temperature, the measurement of circulation, and heat absorption as indicated by fluid density.

IN THE study of the performance of furnaces the Research Committee on Furnace Performance Factors of the A.S.M.E. is developing several testing methods and instrument applications. These methods and applications, although not original with the Committee, are being used on one large boiler at the Tidd Station of the Ohio Power Company. The simultaneous use of these testing methods will permit a comparison which, in turn, will permit an evaluation and selection of that one or more methods necessary for the study of a particular phase of furnace performance. Formerly, overall performance was the only objective but it is hoped that use of these methods will enable study of differences in performance in several zones so as to evaluate each zone with respect to its contribution to overall performance.

Measurement of the Surface Temperature of a Furnace Tube

Measurement of the surface temperature of a metal object can be made by several methods. One, in general use, is that of peening the two wires of a thermocouple into the surface, the temperature of which is to be measured. Provided the thermocouple wires are peened into the surface close enough together so that the metal between them is not likely to vary appreciably in temperature, this method will be accurate. The thermocouple wires should be led away from the point of measurement along an isotherm for a distance at least long enough to minimize the flow of heat along the wires to or from the junction. The most difficult problem in the measurement of the surface temperature of the tubes is the protection of the thermocouple wires in their passage from the point of measurement to the outside of the furnace. Several means have been used to protect these wires. The surface of the tube has been grooved to receive the wire and a cover-plate tacked over the area after the wires were installed. The tube has been chord-drilled and the wires threaded through the holes. The wires have been laid tightly against the tube surface and an internally grooved guard ring welded over them. It is proposed now that the wires be laid tightly against the tube surface and spray-coated with some metal such as aluminum. In several cases some of these couples, protected by a guard ring, are still in use after four years of service.

In a furnace from which part of the ash is removed in a molten state the furnace tubes are coated with a viscous layer of slag, continuously in some zones and intermittently in others. At times this ash coating drops off of its own weight and at other times it is blown off by lancing. Fig. 1 shows the changes in tube surface temperature with time and with some changes in load. A progressive decrease in surface temperature occurred with the passage of time and the accumulation of the ash coating until the seventh day when the coating apparently dropped off because of a change in load. On the thir-

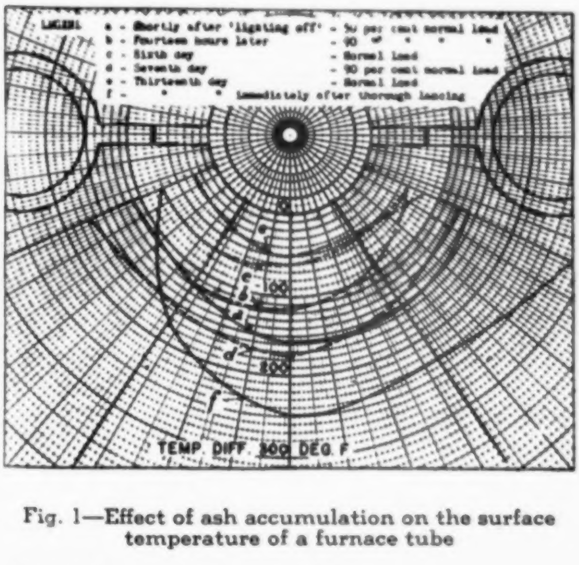

Fig. 1—Effect of ash accumulation on the surface temperature of a furnace tube

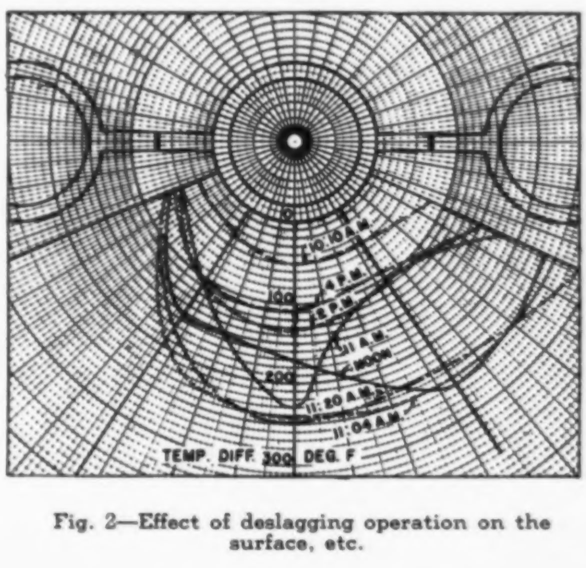

Fig. 2—Effect of deslagging operation on the surface, etc.

teenth day the surface temperatures were quite low but were raised to high values by lancing. In Fig. 2 the conditions before, during and after lancing are shown. Lancing began just before 11 a.m. and the ash coating built up in five or six hours to almost the resistance existing before lancing. It is evident that in a slag-tap type of furnace, tube surface temperatures provide a ready means for a study of the rate of ash accumulation and the effect of the ash coating on heat transmission.

In a dry-bottom type of furnace in which the ash is not removed continuously or in the molten state, less ash builds up on the walls and in most areas of the furnace when the ash does adhere, it is in the form of an unfused powder. The powdered ash is removed by wall blowers but there is evidence to indicate that, with the guard-ring type of installation, the ring holds more of the ash than does the smooth tube. Unfortunately, any ash held by the ring will probably also cover the couple junction and the couple will indicate a lower surface temperature than exists a few inches away from the junction. Under such conditions any study of the variations in the rate of heat transfer along the tube would be based on unrepresentative measurements because of ash deposits in a small area around the junction. To avoid such local deposits the guard rings must be dispensed with and the protection for the couple wires kept as smooth as possible by chord drilling or some similar methods.

At the present time experiments are under way to determine the effectiveness of a sprayed metal, such as aluminum, as a protection for the couple wires. Except for the first cost of the sand-blasting and spraying equipment there is a possibility that this method may be found to provide a lower installation cost than the others. More important, however, than installation cost is the useful life of the couple and this is as yet unpredictable for a sprayed coating.

One of the methods of protecting furnace tubes from attack and wasting now under development is a special coating of aluminum. Because it is impossible to weld a steel guard ring to an aluminum-coated tube without removing or destroying the coating, the spray method of protection has a unique application.

Interpretation of Surface Temperatures

In a paper before the A.S.M.E.[1] the writer and others reported the results of some of the first tests using surface temperatures of tubes as a measure of heat transmission rates. It was found that the drop in temperature from the outside surface to the saturated water on the inside of the tube could be plotted as a straight line against the measured rate of heat transmission. This relationship held for all rates from very low up to 200,000 Btu per sq ft per hr at all pressures up to 3300 psia and for all tube thicknesses from $^1/_8$-in. to $^1/_2$-in. walls. Of course, the temperature drop had to be expressed as degrees per inch of metal to put the different wall thicknesses on a common basis. Although no specific study was made of the effect of internal deposits on the temperature drop, indications of an increase in the drop with increase in dirtiness were noted. It is obvious that the addition of a layer of scale having a high resistance to heat flow will raise the surface temperature of the tube perhaps dangerously for the same rates of heat transmission. Furthermore, even in a clean tube the surface temperature will be higher the thicker the wall. Actually, the temperature drop was found to be directly proportional to the metal thickness as well as to the rate of heat flow. External deposits, such as ash, reduce the rate of heat flow because of their insulating effect without danger to the tube but with possible adverse effects on the superheat. It is clear that in order to protect a tube from the adverse effects with high rates of heat transmission the internal surface must be kept clean at all times and the wall thickness kept small as the design pressure increases. The wall thickness can be made less at any design pressure by decreasing the diameter of the tube. The limitation on tube diameter is circulation resistance and where thin walls are required forced circulation should be used.

By disposing thermocouples circumferentially a study can be made of the heat flux pattern with any given flame direction or firing method. Normally, a crown type of couple is sufficient for a study of the general distribution of furnace heat transmission. The circumferential distribution is of importance, however, in any study of the effectiveness of different wall constructions.

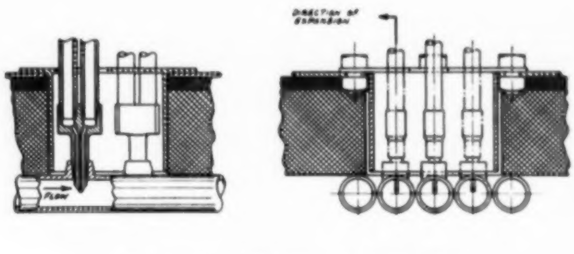

Fig. 3—Installation of pitot tubes

Thermocouples installed for tube-surface temperature measurements have been recorded on the new high-speed flight recorder type of potentiometer and readings of 150 thermocouples made on a strip chart in a matter of minutes. Such records are valuable in determining the effect of variations in other factors on tube surface temperature.

Measurement of Circulation Velocity

Circulation velocities are related to circuit resistances and to heat transmission rates. The circuit resistance retards the velocity of circulation whereas the heat transmission decreases the fluid density by evaporation and provides the pressure differences necessary to move the fluid. In natural-circulation boilers there are often as many as fifty parallel circuits; that is, circuits supplied from a common chamber and discharging into a common chamber. Although the designer attempts to give each circuit of a parallel group the same circuit resistance properties, differences may enter in fabrication and erection. Direct measurement of circulation velocities has been made with the type of pitot tube shown in Fig. 3. Using a high-pressure indicating manometer and dyed carbon tetrachloride as the manometer fluid, suitable observations can be made which with the calibration records can be used to compute the circulation velocity.

The design of the pitot tube should be such as to offer the minimum disturbance to the flow in the tube and the angle of installation carefully checked. Any departure

[1] "Studies of Heat Transmission Through Boiler Tubing at Pressures From 500 to 3300 Pounds," by W. F. Davidson, P. H. Hardie, C. G. R. Humphreys, A. A. Markson, A. R. Mumford and T. Ravese, *Transactions* A.S.M.E., August, 1943.

rom the correct angle will introduce a cosine function orrection and decrease the observed manometer reading. If the flow is not laminar but swirling because of the presence of bends or other obstructions the reading will be of indeterminate value. In other words, inexplicable results have been obtained with this instrument, probably due to error in installation or to swirling flow. In one case an indication of zero flow was obtained continuously with changes in boiler rating and degree of furnace cleanliness, yet the surface temperature of the furnace tube in question was normal and no distress has been noted.

One of these pitot tubes has been installed at the top of a tube where a mixture of vapor and liquid was known to be flowing. It is not known yet whether the indication will be useful or can be interpreted in connection with the velocity indication at the liquid or single fluid end to indicate total heat absorption. However, the reading was steady and may be of value.

Such instruments, when attached to a suitable recorder, make possible an analysis of the changes in circulating velocity with rating, water level, pressure, etc.

Heat Absorption as Measured by Fluid Density

Assuming that the boiler water entering a furnace tube is at the temperature of saturation any heat absorbed will form steam proportionately to the rate of heat absorption. The presence of steam will decrease the density of the fluid in the tube and any device which permits a measurement of the density will furnish data from which the amount of steam in the tube can be calculated. If the entering velocity of the water supplying the tube is also measured the rate of heat transfer along the tube can be calculated.

A simple high-pressure indicating manometer, Fig. 4, has been used to indicate the relative density of the fluid within a tube. Simple connections are installed on the tube to transmit the static pressure from the two selected elevations to the manometer. If the connections are about one foot apart the friction loss between the measuring points will not materially increase the observed difference in static pressure and for such short distances the effect of friction can be neglected without seriously affecting the accuracy. If the connections are comparatively far apart the friction factor should be introduced into the computations. A preliminary estimate of the expected relative density will permit the selection of an indicating fluid of the proper density to give a reading of suitable magnitude for accurate observation.

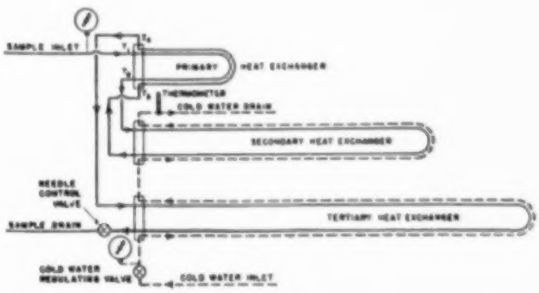

Fig. 4—Installation of fluid density manometers

Another device for the determination of fluid density in a furnace tube is the heat-exchanger calorimeter, Fig. 5. In using this device provision is made for the withdrawal of a sample of the fluid mixture through a standard sampling nozzle. This sample is condensed in a tube-within-a-tube heat exchanger and cooled to a temperature slightly below saturation. The sample is further cooled to a desired temperature in a second similar heat-exchanger. The cooling water is connected for series flow eliminating any necessity for weighing cooling water or condensate. Observations of temperature at inlets and discharges of each heat-exchanger are made by the use of calibrated thermocouples installed in thermometer wells. For greater accuracy a special potentiometer is advised for these measurements. A simple heat-balance equation can be set up for the temperatures available which permits the direct computation of the percentage of steam by weight in the sample. There can be no assurance, of course, that the sample is representative until agreement is established with independent method of measurement.

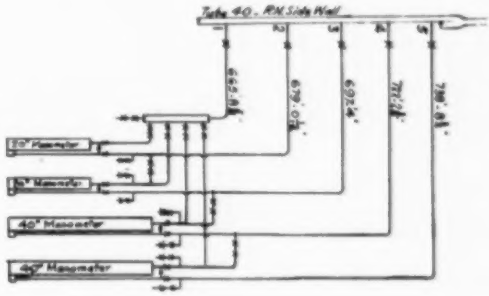

Fig. 5—Schematic arrangement of heat-exchanger calorimeter

Combined Surface Temperature, Circulation Velocity, Fluid Density and Calorimetric Measurements

At the Tidd Plant one furnace tube was selected on which are made all four types of measurement of quantities from which heat absorption rates could be computed. Computations of all methods have not yet been completed but the indications are that substantial agreement will result. Such agreement will generally confirm the substantial accuracy of each method and permit a choice of that one most easily installed for future work.

In the work at this plant a survey is being made of the gas temperature, composition and velocity of the gases leaving the furnace. These measurements are taken independently by the U. S. Bureau of Mines Staff but are taken simultaneously with the other types of measurements. Thus, the relative accuracy and the absolute accuracy of the method of sampling the entire furnace can be determined.

It may be self-evident that a failure does not occur because of average conditions but does occur because of an abnormal or subnormal condition at some point in the furnace system. These developments of instrumentation for the study of furnace performance are for the purpose of breaking down average conditions into their abnormal and subnormal components for the better understanding of the performance of a furnace and the avoidance of bad abnormal or subnormal conditions.

UNDER-BUNKER CONVEYORS*

The author outlines the functions of under-bunker conveyors, describes typical arrangements, illustrates certain undesirable arrangements, and lists the requirements for a well-designed conveyor of this type.

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Stock Engineering Company

THERE are five basic reasons for the employment of "under-bunker conveyors," which are conveyors installed under a coal bunker or between a bunker and the point of use of the coal. These may be enumerated as follows:

1. To feed coal to stokers or pulverizers which are so located in relation to the bunker outlets that coal cannot be fed to them by gravity. An illustration of this necessity for an under-bunker conveyor would be a boiler house equipped with a silo or bunker which is located at one end of a row of boilers. The conveyor carries coal from the silo or bunker down the line of boilers. A conveyor used for such an arrangement must be absolutely reliable since the plant cannot operate without it. It is usually desirable for plants of this design to have two conveyors in order to insure against failure of either one.

A modification of this plant arrangement is one in which the silos or bunkers are located in front of the boilers with one silo to one, two or three boilers. A separate conveyor is generally used to convey the coal to each point of use. Reliability of conveyor operation here is also important, but not as important as in the plant arrangement previously mentioned, since each conveyor feeds only a portion of the line of boilers, and, therefore, failure of only part of the plant capacity can result from the failure of any one of the conveyors.

2. To reclaim coal from the "dead spots" which exist between the principal bunker outlets. These dead spots are usually largest in that portion of a continuous bunker which is between the boilers.

3. To reduce the frequency of coal-loading operations. Small bunkers necessitate an arrangement which will allow any coal not needed by one boiler to be made available to the other boilers, in order that the intervals between the loading of coal into the bunker may be as long as possible.

The modern trend of installing one or two high-capacity boilers in an old boiler house in conjunction with old existing boilers often creates a need for an under-bunker conveyor. Since the new high-capacity units carry most of the load of the plant and are on the line most of the time, they must obtain their added coal requirements by means of a conveyor from that part of the bunker in front of the smaller boilers.

4. To quickly and easily empty any section of the bunker for repairs or the prevention of bunker fires. Certain types of coal which are very subject to spontaneous combustion require some means of removing the coal from the bunker when the boiler is shut down. Sometimes these shutdowns are not scheduled, and if no means are provided to empty the bunkers, a bunker fire can easily result.

5. To make possible the operation of the boiler plant for the maximum number of hours in the event of a breakdown of the equipment which elevates and conveys coal to the bunker. An under-bunker conveyor makes practically all of the coal in the bunker available to all the boilers in service. It is, of course, possible to move coal within the bunker by hand, but this requires manual labor, which in the event of a breakdown will probably be difficult to obtain. Such a conveyor adds materially to the reliability of the overall plant if installed for this purpose.

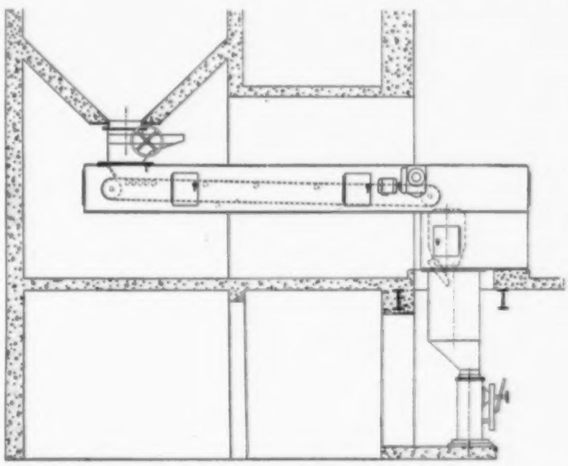

Fig. 1—Automatic coal scale with single elongated feed belt used as a conveyor

Under-bunker conveyors must be designed to suit the individual requirements of every plant. There are, however, several more or less typical designs which fit the requirements of many plants. These are illustrated in Figs. 1 to 7, inclusive.

Fig. 1 shows an arrangement by which coal is received from a bunker outlet not more than 20 ft horizontally from a single point of use. The coal scale illustrated is equipped with an elongated feed belt which acts both as an under-bunker conveyor to transport the coal from the bunker outlet to the point of use and as a coal scale feeder. The scale feed belt is started and stopped by the scale control, which thus keeps the hopper beneath the scale full of coal at all times. Installations of this type usually achieve reliability by the provision of duplicate feeding equipment.

In order to reclaim coal from those parts of a continuous bunker which are not immediately in front of a boiler, it is often possible to employ a coal scale with two elon-

* From a paper before the Ninth Midwest Power Conference.

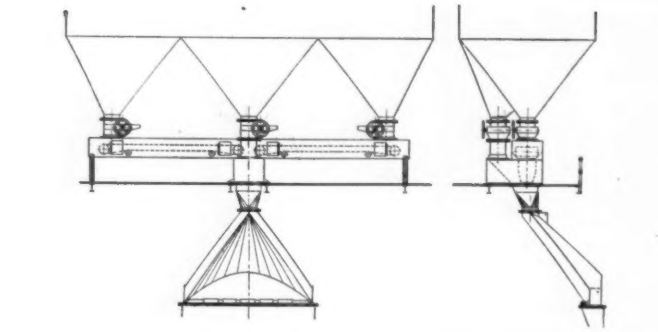

Fig. 2—Automatic coal scale with two elongated feed belts used as a double conveyor

gated feed belts. such as is shown in Fig. 2. This coal scale is arranged to receive coal from two bunker outlets, one outlet to each feed belt. With the arrangement as illustrated, boiler operation reliability is achieved by means of a center bunker outlet, which allows coal to be by-passed by gravity around the coal scale and its feed belts; consequently any mechanical or electrical failure of the coal scale or its control equipment will not cause a shutdown of the boiler unit.

It is often necessary to reclaim coal from a long continuous bunker parallel to a line of boilers and make coal in front of one boiler available to any of the other boilers. The solution to such a problem is illustrated in Fig. 3. This layout shows a typical "bunker-to-stoker" arrangement, with the exception of the coal valve which instead of being a single valve is in reality three valves and a short section of conveyor, all built in one housing. In the end elevation, the left-hand portion of the triple valve, when opened, allows the coal to flow by gravity in a straight vertical line from the bunker outlet to the coal scale inlet. This is the normal method of feeding coal to the scale.

However, when it is desired to transport coal from this bunker outlet to another boiler, the top right-hand portion of the triple valve is opened, allowing coal to flow in a straight vertical line from the bunker outlet down onto the conveyor chain. This conveyor is a typical, dust-tight, drag flight unit. Coal is conveyed by the chain from the point under the open valve to the takeup end, where it falls from the upper chain to the lower chain. The lower chain moves the coal toward the conveyor head sprocket and discharges it at any point or any number of points where the discharge valves have

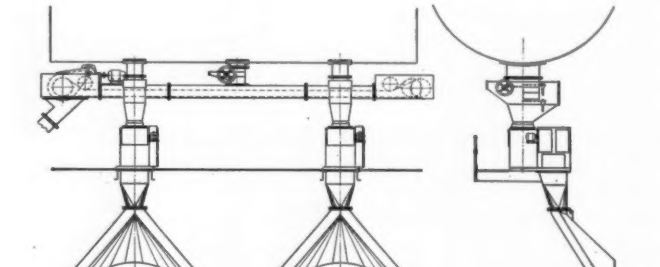

Fig. 3—Typical bunker-to-stoker arrangement with triple valve and under-bunker conveyor

been opened. The discharge valve is shown in the end view of Fig. 3 in the lower right-hand portion of the triple valve assembly. Intermediate points of feed and discharge can easily be arranged.

Fig. 4 shows a typical bunker-to-stoker arrangement without coal scales, but with a triple valve similar to that in Fig. 3, and a drag conveyor. The direct vertical feed to the conical distributors is through the left-hand section of the triple valve; feed to the top strand of the conveyor is through the top right-hand section of the triple valve; and discharge from the lower strand of the conveyor to the conical distributors is through the bottom right-hand section of the triple valve.

This same arrangement can also be employed to reclaim coal from those parts of a bunker which will not feed coal by gravity to the desired points of use. Such an arrangement is illustrated in Fig. 5 which shows a conveyor installation in a plant originally designed for eight small boilers. All these small boilers were removed and two high-pressure boilers installed in their stead.

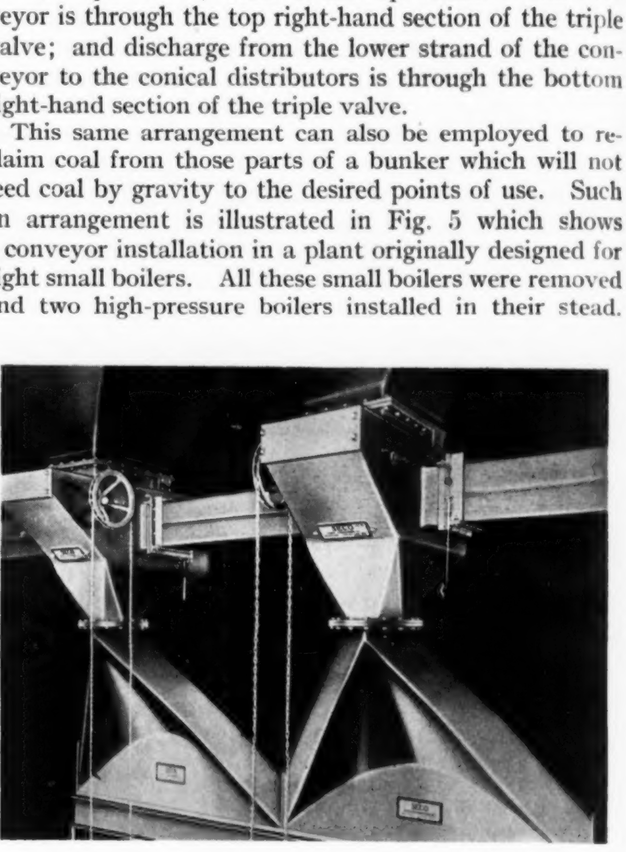

Fig. 4—Photograph of typical bunker-to-stoker arrangement with triple valve and under-bunker conveyor

Inasmuch as the two new boilers could only obtain half of their coal requirements from the bunker by gravity, some form of under-bunker conveyor was necessary. Two triple valves and a drag flight conveyor, similar to those shown on Fig. 3 and 4, were installed and arranged to meet the requirements of this plant.

Automatic control is often needed to insure the proper feeding of the automatic coal scale, the pulverizer, or the stoker. The control for the starting of an under-bunker conveyor may consist of a swing switch installed directly over the feed belt of a coal scale. Fig. 6 shows a cross-section of a swing switch mounted on top of an automatic coal scale. A vertical paddle, usually made of stainless steel, is rigidly attached to a horizontal shaft which turns freely in flange-mounted ball bearings. While coal maintains its normal level on the scale feed belt, the stainless steel paddle is held in an inclined position. When the coal on the feeder of the coal scale is exhausted, the paddle swings to the vertical position, thus indicating that coal is required by this scale. The turning of the horizontal shaft actuates a mercury switch and starts the under-bunker conveyor. The conveyor is stopped by a stop-switch which is similar in construction

to that illustrated in Fig. 6, but which is usually located in the lower part of the triple valve instead of in the scale.

In many plants it is necessary to transport coal from one part of the bunker to a point of use at which there is insufficient headroom to use any of the preceding feeding arrangements. In this event, it is often necessary to recirculate the coal to a point in the bunker directly above the desired point of use. Such an arrangement is illustrated in Fig. 7. The plant illustrated had installed two low- and one high-pressure stoker-fired boilers, each of which was equipped with coal scales and conical distributors in the usual bunker-to-stoker arrangement. Inasmuch as the right-hand boiler was the new high-pressure unit and could usually carry the full load of the plant, it was expected that its steaming hours would be the maximum possible. The other two boilers were to be used as stand-by units only. Therefore, some means of taking the coal from the left-hand part of the bunker and feeding it to the high-pressure, right-hand boiler was necessary. Or, if the new high-pressure boiler was not being used, some method was required to take the coal from the right-hand part of the bunker and convey it to the left-hand part. Headroom was not sufficient for a horizontal drag chain type of under-bunker conveyor.

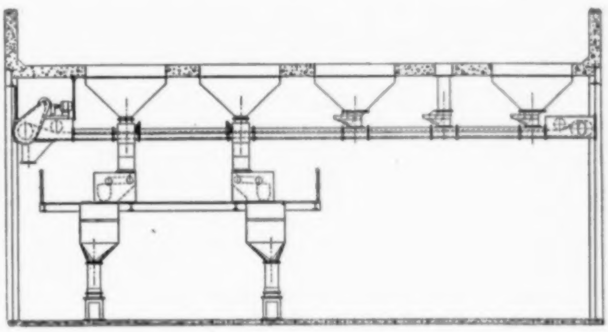

Fig. 5—Bunker-to-pulverizer arrangement with boilers at one end

In order to accomplish the desired result, a vertical run-around, gravity discharge conveyor was installed. This gravity discharge conveyor was fed from four bunker outlets by four horizontal belt feeders. Coal can thus be removed from any of the four bunker outlets and returned to that part of the bunker consistent with the boiler or boilers in operation.

A somewhat similar arrangement to Fig. 7 has proved to be very successful in many plants which are equipped with Peck carriers to relocate the coal in the bunker. Using this type of conveyor, it is possible to make connection between any number of outlet points in the bunker and the lower strand of the conveyor. The conveyor re-elevates the coal and discharges it at the points required. Such an arrangement gives great flexibility in making all of the coal in a bunker available to the stokers or pulverizers.

In some cases where under-bunker conveyors have been used, their design has not been given sufficient thought to insure continuity of boiler operation. It will be of value, therefore, to show illustrations of some such layouts that have been considered in order that one may benefit from the mistakes in design that have been made. These illustrations are not the designs of any particular manufacturer.

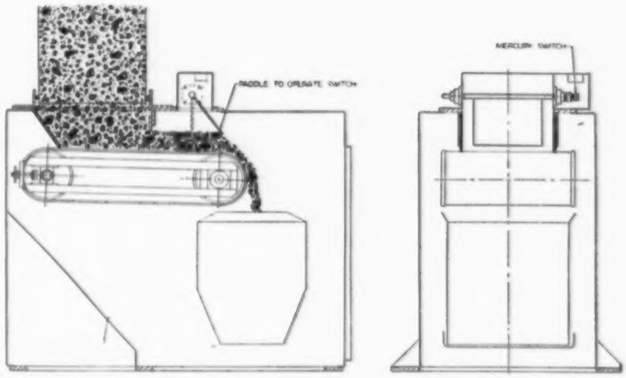

Fig. 6—Swing switch arrangement

Fig. 8 shows an arrangement of an under-bunker conveyor which was designed for the purpose of making available the coal between the principal bunker outlets of a continuous bunker. This arrangement consisted of a screw conveyor with the necessary connecting chutes. The feed portion of the conveyor was a 6-in. diameter screw, while the conveying portion was a 9-in. diameter screw. The bunker outlet coal valves and the chutes that directly connect the main coal valves with the coal scale inlet were 16 in. square. The chute between the coal valve and feed screw was $5^3/_4$ in. in width at its lower end. Specifications called for the use of a varying mixture of $1^1/_2$-in. nut and slack coal.

The design size of both the feed screw and the conveyor screw is so small that if the coal mixture consisted mostly of the $1^1/_2$-in. nut size coal, or mostly of slack coal with a high moisture content, the coal would arch in the narrow feed chute and would not feed to the feed screw. In other words, good results cannot be expected from this design of under-bunker conveyor, because of the small size of the feed screw and the conveying screw, and the narrow width of the chute between the bunker outlet and the feed screw.

Fig. 9 illustrates another example of poor design. It shows the end elevation of an installation which was designed to feed from an 18-in. round bunker outlet to a 16 × 20-in. coal scale inlet. The width of the coal stream was reduced to $5^3/_4$ in. in order to permit passage through a horizontal run-around conveyor. Wet, fine, sticky coal cannot be expected to pass through any chute that has a width of only $5\frac{3}{4}$ in., particularly a chute with the further obstruction of a run-around conveyor chain. This installation should have been designed with

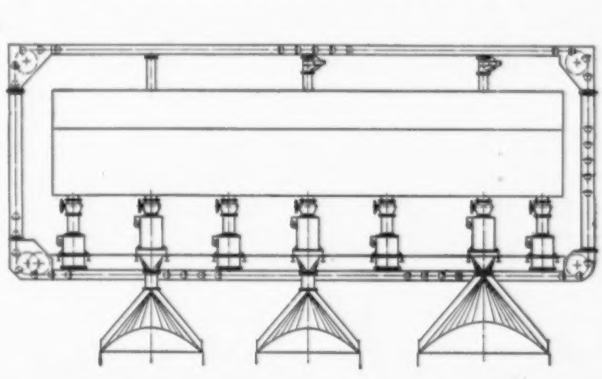

Fig. 7—Method of relocating coal in a bunker by means of a gravity discharge type of under-bunker conveyor

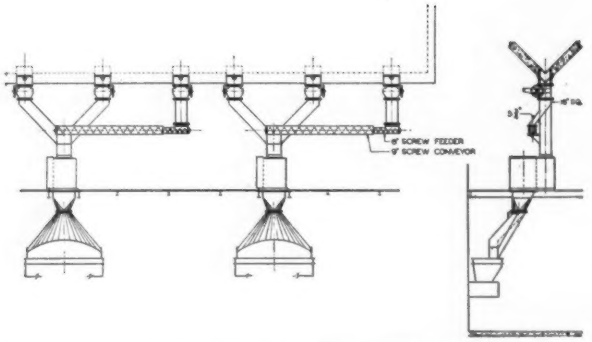

Fig. 8—Arrangement of an improperly designed screw conveyor used to reclaim coal from dead spots between principal bunker outlets

a direct gravity connection between the bunker and the coal scale, a larger connection to the conveyor, and a larger conveyor.

This arrangement was originally designed with the thought in mind that the conveyor would run continuously and circulate coal in the horizontal run-around housing. It was found that this circulation was not satisfactory and, therefore, the control of the conveyor was changed so that the conveyor was used to transport coal from one place to another.

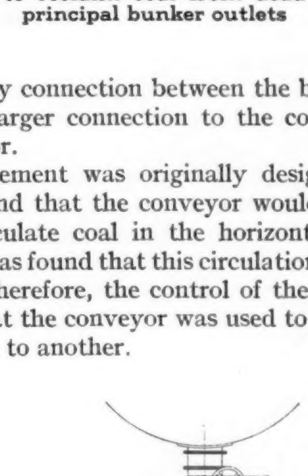

Fig. 9—Arrangement of improperly designed horizontal run-around conveyor with narrow entry chute

Fig. 10 illustrates a third poorly designed underbunker conveyor arrangement which would cause serious operating difficulties. The purpose as designed was to weigh enroute the coal between the bunker and the stoker hoppers and also to make all the coal in the bunker available to any stoker. In order to accomplish this result, it was proposed to furnish a coal scale with an elongated feed belt which would receive coal from a number of bunker outlets. The coal scale would discharge to a screw conveyor which would in turn discharge the coal to three stoker hoppers. The entire operation of the plant is dependent upon the day-in-and-day-out operation of an elongated feed belt of a scale and a screw conveyor. Any failure of either of these pieces of equipment, or any failure of the coal scale itself, would cause a failure in the coal feed to the stokers. There is only about a 15 or 20 minute coal supply in each of the three stoker hopper extensions, and if the failure of either of the two long conveyors could not be repaired in that short period of time, the entire plant would be shut down. It should also be noted that the arrangement of a screw conveyor discharging to the top of a stoker hopper would cause coal segregation. In the case at hand, coarse coal would be segregated on the left-hand side of the stoker hopper and the fine coal would predominate on the right-hand side.

List of Requirements

To summarize the various requirements for a well-designed under-bunker conveyor, the following requirements may be listed:

1. Horizontal cross-section of chutes to conveyors, conveyor inlets, and the conveyors themselves when normally run full of coal, should be at least 15 or 16 in. square.
2. The thickness of steel plate used in the conveyor housing should be such as to give good life, particularly in sections of the country burning high-sulphur coal which is very corrosive when wet. Plate of $^1/_4$-in. thickness should be considered the minimum, while $^3/_8$-in. thickness of plate is preferable.
3. The conveyor housing should be dust-tight.
4. Hinged, gasketed, access doors should be provided at every point required for inspection or servicing, and should be equipped with suitable latches.
5. Each conveyor should preferably be fed from only one inlet at a time.
6. If more than one coal inlet is used per conveyor, provision should be made for increasing the space provided for the coal as it flows past additional inlet openings.
7. An alarm should be provided in conjunction with the conveyor installation so that if the supply of coal is exhausted at the one bunker outlet in use, the operator is notified to open another bunker outlet.
8. Conveyors should be designed for point-to-point transportation of coal. The conveyor should not attempt to circulate the coal continuously
9. Conveying systems should be designed so that the plant can operate for a maximum period in the event of possible conveyor failure.
10. Surge hoppers between a conveyor and a scale, or between a conveyor and either a stoker or pulverizer, should have a capacity such that the conveyor is not started and stopped more than necessary.
11. The conveyor discharge should not cause coal segregation in stoker hoppers.
12. The design of chutes and downspouts should be such that the possibility of coal sticking or clogging is reduced to a minimum.

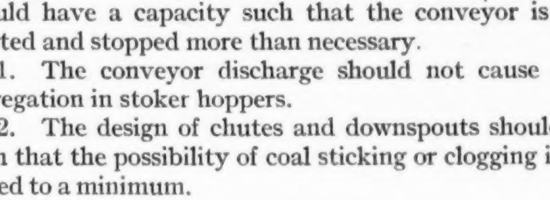

Fig. 10—Arrangement of elongated coal scale feed belt discharging to screw conveyor

13. The design of feed connections to the conveyor should be such that any water draining out of the bunker will not collect in the conveyor.

14. The control of the conveyor should be automatic.

15. Automatic controls should be reliable, despite the dirty and corrosive conditions in which they operate.

16. The automatic controls should be so located that proper operation is assured.

17. The appearance of the installation must be neat as this equipment is on the front of the boiler. Ungainly structural supports are undesirable.

18. Feeding capacity of the conveyor should be only slightly more than the maximum burning capacity of the boiler or boilers being fed. Too high a conveyor capacity means too many starts and stops of the conveyor.

19. The location of conveyor parts, chutes, valves, supports and other related equipment should be such that operators cannot injure themselves on projecting corners or eye-level obstructions.

In many plants, under-bunker conveyors are installed only as an auxiliary method of feeding coal to the boilers. With this in mind, many engineers feel that it is not necessary to make the conveyor installation in a first-class manner, but will instead trust that some compromise arrangement will prove to be satisfactory. The writer feels that such an attitude is an unwise policy since sound boiler-room practice demands that all equipment in a boiler room should always be reliable and ready for operation if an emergency arises.

THE PRODUCTS OF CORROSION—Iron Oxides, Hydrated Oxides and Hydroxides

This article discusses those phases of corrosion research where systematic studies of the products of corrosion are most needed to provide a better understanding of the mechanism involved; also in so far as is known, the chemistry of the products formed by corrosion of iron and steel under some conditions met in power plant practice; and suggests the data that are needed to determine the essential properties of corrosion products. Subsequent articles will discuss nonferrous metals.

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THE conventional weight-loss test of a metal to determine its corrosion rate under specified conditions supplies only an end-result, and rarely is a sufficient clue to the mechanism of attack; that is, the chemical and physical changes which occur at the surface of the metal during its contact with the corroding medium. For some engineering purposes it is sufficient only to know the extent the metal will be attacked in a given time. But usually the best solution requires, in addition to the rate of corrosion, knowledge of the mechanism of attack, since it is then that preventive measures can be devised upon a more substantial basis than trial-and-error.

Of the factors that determine the mechanism of attack on a metal or alloy, the most important are: (*a*) the change of weight at regular intervals of time, establishing if the rate of change is a linear, parabolic or logarithmic relation; (*b*) the change of emf of the metal against a suitable solution with time, affording information on the polarization, or film-forming characteristics of the metal under the stated conditions; and (*c*) the chemical and physical properties of the solid products formed at the site of corrosion. Time-potential measurements, which have been described elsewhere [1][1] can only be made when the medium that the metal is in contact with is a conducting liquid. However, in nearly all cases of corrosion by liquids and by hot gases and vapors, the rate of corrosion can be determined, and there is a sufficient quantity of a corrosion product formed that can be analyzed by one or more of the methods to be described later. It is the latter phase of corrosion studies that has received the least attention from corrosion investigators and with which the following discussion will be primarily concerned.

[1] Numbers in brackets refer to bibliography at end of article.

Corrosion is a process in which metals or alloys react with the liquids, vapors or gases comprising the environment, and form oxides, hydrated oxides, sulfides, salts, or complex combinations of these constituents. There is sufficient experimental evidence that the properties of these materials, particularly the solubility, crystal structure, chemical composition, porosity and heterogeneity, all have a part in determining whether the products will continue to form until the metal is completely destroyed, or whether they will become protective and gradually stifle attack.

One of the significant uses for the chemical properties of corrosion products is in thermodynamic studies of corrosion systems, which provide a method for determining the spontaneity or tendency for a given corrosion reaction to take place. Warner [2], however, suggests that, due to a lack of information on the solubility and chemical composition of a variety of corrosion products, there have been difficulties in applying thermodynamic methods to a number of important corrosion reactions. This has been particularly true in the case of iron oxides, hydrated oxides and various complex iron compounds. In some of the compounds such as goethite (α-FeOOH) and lepidocrocite (γ-FeOOH), which occur on iron under relatively ordinary conditions, the chemistry has been fairly well established, but they have not been produced under controlled laboratory conditions so that the thermodynamic properties could be determined and correlated with the service conditions. In addition to the oxides and hydrated oxides, there are numerous other corrosion products that contain chloride or sulfate ions in appreciable quantities; particularly those that occur on structural parts exposed to marine and industrial atmospheres. Frequently such corrosion products are referred to as "basic chlorides" or "basic sulfates," but in so far as the writer is aware there has been no systematic study to establish their identity by means of petrographic and X-ray diffraction studies. If this information were available, and the compounds could be reproduced in the laboratory under the same conditions that they are formed in service, the thermodynamic properties could be determined and form a valuable step toward discovering the mechanism of attack.

Due to lack of data on corrosion products, chemical compositions often have been assumed that have no basis

in fact. As a result, the calculated thermodynamic free energy values suggest spontaneities that are not observed in practice.

There are two general classes of corrosion for which systematic studies of the corrosion products are needed, namely, the corrosion of metals and alloys by humid atmospheres and by hot gases and vapors at temperatures above those at which liquid phases are present.

Corrosion in Humid Atmospheres

With regard to humid atmospheres, an extensive program of work has been in progress for several years in this country and abroad to study the relative corrosiveness of rural, marine and industrial atmospheres toward a variety of structural metals. For each type of atmosphere comparisons have been made between bare and coated metal surfaces; particularly surfaces prepared by bonderizing, Parkerizing, chromizing, metal-spraying, cladding and terne- or electroplating. Valuable qualitative and semi-quantitative results have been obtained from these studies, but in general there is a notable lack of data on the chemical and physical properties of the corrosion products that were found.

In a recent investigation [3] several ferrous materials were exposed to rural, marine and industrial atmospheres for one year. The attack was classified according to the roughness and color of the rust, and the author concluded, "... the darker the color, the more protective the oxide." The value of the data would have been greatly enhanced had a correlation been sought between the physical properties and the chemical composition of the rusts, analyzing each one chemically and by means of X-ray diffraction.

Another case where a chemical and X-ray diffraction analysis of corrosion products would have afforded valuable supplementary information is to be found in a recent investigation [4] of the corrosion of pure metals, electroplated coatings on copper, copper alloys, chromium alloys and nickel alloys in and around a refinery atmosphere. The relative amount of corrosion was rated, in this case, according to the amount and color of the corrosion products, and the degree and distribution of pitting that occurred.

Various investigations of the corrosion of copper-alloy steels in different atmospheres have shown that a small chloride component in the atmosphere frequently causes rapid attack of alloys which otherwise had good atmospheric corrosion resistance. Although there has been considerable conjecture regarding the effect of chlorides in the attack of this type of steel, the writer has been unable to find any work in which the manner that the chloride is combined has been determined.

Copson [5] has recognized the importance of the physical and chemical properties of the corrosion products formed on iron and low-alloy steels in marine and industrial atmospheres. On the basis of an investigation begun in 1941, and still in progress, he has proposed a theory for atmospheric rusting based upon determinations of the iron, sulfate, chloride, copper and nickel content of the rusts. He states "In the literature it seems to have been tacitly assumed that in a given atmosphere each piece of steel is exposed to the same environment. Actually since corrosion products influence the amount of soluble salts (in contact with the metal) each steel is exposed to a separate environment. Since the corrosion products are determined partly by the composition of the steel, their composition becomes of paramount importance." This investigation is not yet complete, but it is hoped that when the corrosion products are finally evaluated the X-ray diffraction and petrographic analyses will be included.

Corrosion by Hot Gases and Vapors

The relation of the composition of scale formed on metals and alloys by hot gases and vapors to the mechanism and rate of oxidation has received some attention. A recent article [6] which discussed the current theories of high-temperature corrosion, described how studies of the composition of scale, particularly the distribution of the individual constituents, have led to rational explanations for the role of alloying elements in metals developed for high-temperature service. To illustrate the importance of scale composition, it is desirable to mention some of the principal factors that control the rate of oxidation of metals and alloys at high temperatures:

1. The rate of diffusion of the oxidizing gas (oxygen, steam, sulfur oxides, hydrogen sulfide, etc.) to the metal- or oxide-gas interface.
2. The rate of diffusion of metal ions outward through scale to oxide-gas interface.
3. The rate of diffusion of gas molecules, atoms or ions through the scale to the oxide-metal interface.
4. The nucleation and growth characteristics of the scale.
5. The relative specific volume of the scale and the parent metal.
6. The recrystallization characteristics of the scale.

Which of these factors controls the rate of oxidation for a given set of conditions, depends to a large extent upon the specific nature of the oxide or oxides formed; particularly the type of crystal lattice. If it is a "defect" type, such as occurs in FeO and FeS, the diffusion rates are higher than in the case of "ionic" lattices, represented by Al_2O_3 and SiO_2. Therefore, if the constituents comprising the scale impede diffusion of metal atoms outward and gas atoms inward the rate of oxidation will be lower than when these constituents are absent.

In the oxidation of chromium-iron alloys by air, it has been found [7] that due to chromium having a greater tendency to oxidize than iron, the initial rate of corrosion of such alloys is greater than that of iron alone. However, as the concentration of chromium in the scale increases it becomes an effective barrier to diffusing atoms in the scale, and the rate of oxidation rapidly decreases. The ratio of chromium to iron in the scale of chrome-iron alloys usually is much higher than in the parent metal.

The latest paper [8] of a series dealing with the corrosion of alloy steels by high-temperature steam states that the concentration of chromium, silicon and molybdenum is higher in the scale on Cr-Mo-Si steels than in the parent steel after 500 hr in 1500-F and 1730-F steam. Further, it was found that the scale was decidedly heterogeneous, the portion of the scale nearest the metal having higher concentrations of these elements than the outer portion.

The significant fact derived from these studies is that the effect of the alloying elements is not additive, few

generalizations regarding the specific effect of any one element being possible. X-ray diffraction studies of scale from numerous alloys have shown repeatedly that the oxides rarely are present individually, but are associated with the other metallic oxides in a complex manner. It is in such cases that the X-ray diffraction, or electron diffraction technique, is unique since chemical analysis does not show how the elements are combined.

In the foregoing discussion contact of the metal directly with the oxidizing gas was considered. Another phase of high-temperature corrosion of increasing importance is where a nonmetallic solid phase is present between the metal and the gas—this phase having been deposited on the metal from the gas stream. It is recognized, for example, that under certain conditions deposits on preheater plates, economizers and furnace tubes, consisting largely of alkali metal sulfates, have an important bearing on the corrosion of these parts. Extensive chemical and X-ray diffraction analyses of the deposits associated with external corrosion of furnace-wall tubes of slag-tap furnaces [9] led to an explanation of attack. These deposits, consisting primarily of a solid solution of sodium and potassium sulfate, condense on the tubes from the flame or are distilled from the slag. Then, as the result of the combined action of these sulfates and sulfur trioxide evolved from the coal ash on the tubes during slagging reactions, the normal oxide on the tubes reacts to form a complex compound:

$$3K_2SO_4 \text{ (deposit)} + Fe_2O_3 \text{ (normal oxide)} + 3SO_3 \text{ (slagging reaction)} \rightarrow 2K_3Fe(SO_4)_3$$

The continuous removal of the oxide to form this compound results in a higher rate of corrosion of the tubes than would occur if the alkali metal sulfates were not present. The reaction has been duplicated in the laboratory, simulating the conditions under which it occurs in a furnace, and the X-ray diffraction patterns of the synthetic product have been found to be identical with those of actual deposits indicating the phases formed to be the same.

It is apparent from the few examples cited that the chemistry of corrosion products is not simple. In the case of ferrous corrosion, which far exceeds that of any other metal, it is frequently assumed, without confirmation, that a certain scale is ordinary rust or magnetic iron oxide. To do this, however, is to assume for the corrosion products of iron a simplicity that does not exist, and it is the purpose of the discussion that follows to describe the pertinent chemical and physical properties of the oxides, hydrated oxides and hydroxides of iron.

Chemistry of Iron Oxides

The complex interrelations of the oxides, hydrated oxides and hydroxides are given in Fig. 1, which is a modification of a scheme proposed by Welo and Baudisch. Roughly, the compounds are arranged according to their stability, the most easily oxidized at the top and the most stable at the bottom. The gradations in reducing potential of members on the same level are not indicated, since in most cases no data are available.

1. **Ferrous Hydroxide, Fe(OH)$_2$.** When hydroxyl ion is added to a ferrous salt in the complete absence of dissolved oxygen, at ordinary temperatures, ferrous hydroxide (sometimes referred to as ferrous oxide monohydrate) occurs as a white, flocculent precipitate. Inasmuch as it has a high affinity for oxygen, changing instantaneously to a greenish-black, black, or red substance in the presence of minute amounts of dissolved oxygen, and readily reduces many other substances it is rarely seen in its pure form. From dehydration studies it has been concluded that there is one molecule of water in the crystal lattice, but there is no certainty as to the manner in which it is arranged. X-ray diffraction analysis shows the crystal structure to be rhombohedral, with lattice parameters of $a = 3.24$ and $c = 4.47$ angstrom units. The specific magnetic susceptibility,[2] χ, is $+20 \times 10^{-6}$ cgs units.

Of the iron oxides and hydrated oxides that are known, ferrous hydroxide is the least well understood. Such fundamental properties as the solubility in water and the solubility product constant, Ksp, have not been definitely established; the literature reporting solubilities from 0.02 to 3.75 ppm, and Ksp values from $10^{-18.8}$ to $10^{-14.5}$.

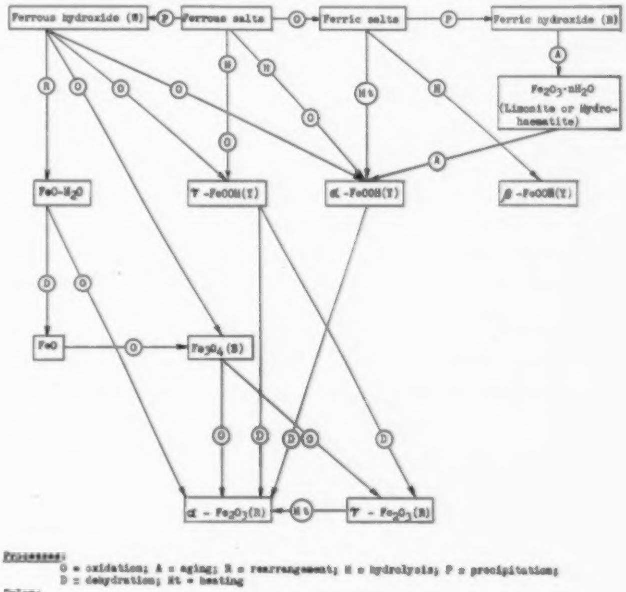

Fig. 1—Reactions of iron oxides, hydrated oxides and hydroxides

These inconsistencies have raised doubts about the validity of the fundamental reaction that has been assumed for the corrosion of iron by pure water in the absence of oxygen:

$$Fe + 2H_2O \rightarrow Fe(OH)_2 + 2H_2 \quad (1)$$

Recent laboratory [11, 12, 13], theoretical [14] and full-scale power plant studies [15] have suggested that the final product is Fe_3O_4 instead of $Fe(OH)_2$, occurring according to the reaction:

$$3Fe + 4H_2O \rightarrow Fe_3O_4 + 4H_2 \quad (2)$$

It is possible, however, that $Fe(OH)_2$ occurs first,

[2] The magnetic susceptibility is an important property for the identification of compounds. Therefore, where the data are available, the χ-values of the compounds to be described will be stated. Glasstone [16] gives an excellent elementary discussion of dia-, para- and ferromagnetism, and the units of measurement. For the present purposes it is sufficient to mention that χ is positive and of the order of 10^3 units for ferromagnetic substances and 10^{-6} for paramagnetic substances; for diamagnetic substances it is negative and of the order of 10^{-6} units.

according to reaction 1, above, and then decomposes to Fe_3O_4 and more hydrogen according to:

$$3Fe(OH)_2 \rightarrow Fe_3O_4 + 2H_2O + H_2 \qquad (3)$$

Then if reaction 1 were faster than 3 a certain concentration of $Fe(OH)_2$ would be present at any instant, but if reaction 3 were faster than 1 no $Fe(OH)_2$ would be observable at any time. The following considerations offer some support to this hypothesis:

First: It has been demonstrated [16] that $Fe(OH)_2$ is not stable. In Fig. 1 it is shown that the molecule of water undergoes an irreversible rearrangement, the mechanism of which is not fully understood, with the net result that the activity of $Fe(OH)_2$ decreases with time. For example, in the presence of oxygen, aged $Fe(OH)_2$ oxidizes to α-Fe_2O_3, but freshly precipitated it oxidizes to Fe_3O_4 in alkaline solutions and to α-FeOOH in neutral or slightly acid solutions. Under certain conditions, to be described later, the final oxidation product is γ-FeOOH. Although the relation of these spontaneous changes to the foregoing reactions 1, 2 and 3 is not evident at the present time, it is significant that the water molecule effects certain changes in the properties of $Fe(OH)_2$.

Second: In two of the investigations cited, small amounts of dissolved ferrous ion were found simultaneously with Fe_3O_4 in systems where iron was in contact with pure, oxygen-free water. In one [13] iron was in contact with the water for over three months, and in the other [15] the iron was washed continuously with pure condensate used for boiler feed. In the latter investigation, dissolved iron and hydrogen balances suggested that ferrous hydroxide was carried into the boiler from the feedwater system and decomposed to Fe_3O_4 and hydrogen.

Third: It has been demonstrated [17] that $Fe(OH)_2$ decomposes to Fe_3O_4 and hydrogen in pure, oxygen-free water (see equation 3). The rate that this occurs varies inversely with the initial pH of the water, suggesting that hydroxyl ion tends to stabilize the $Fe(OH)_2$. This may explain why investigations in neutral systems have shown Fe_3O_4 to be the end-product.

The final word has not been said with regard either to the mechanism of corrosion of iron in pure, oxygen-free water, or to the effect of temperature and pH on the rate of corrosion. Clearly an exhaustive study of the properties of $Fe(OH)_2$ is needed, particularly its solubility, Ksp, crystallography and behavior at various temperatures and pH.

2. Ferric Hydroxide, Fe(OH)$_3$. In a strongly oxidizing solution ferrous hydroxide changes to ferric hydroxide, a reddish-brown, flocculent and insoluble precipitate. The crystal structure, for reasons which will be mentioned later, is not well established. It is paramagnetic, with $\chi = 116 \times 10^{-6}$ units when freshly prepared. Structurally, ferric hydroxide is complex and unstable. Studies have shown, as indicated in Fig. 1, that it converts spontaneously to limonite or hydrohaematite, hydrated forms of Fe_2O_3, in which the number of mols of water is not definite and whose X-ray diffraction patterns are diffuse, suggesting latent but incomplete order in the crystallites. Further aging converts the limonite and hydrohaematite to a well-defined, crystalline compound, goethite (α-FeOOH). For these reasons it is unlikely that $Fe(OH)_3$ ever occurs as a constituent of rust.

3. γ-Ferric oxide hydrate, γ-Fe(OOH) (Lepidocrocite). Fig. 1 shows this compound also to be an oxidation product of $Fe(OH)_2$, under special conditions. Generally it has a light brown to yellow color. X-ray diffraction studies have shown the crystal structure to be identical with the mineral lepidocrocite, belonging to the orthorhombic system and having only Fe^{+++}, $O^{=}$ and OH^- ions in the lattice. Comparison of the spacings of the planes (d-values) giving the three strongest X-ray reflections, with those of the others given in Fig. 2, shows it to be uniquely different. The lattice constants are $a = 3.27$, $b = 12.4$ and $c = 3.06$ angstrom units. It is paramagnetic, $\chi = +42 \times 10^{-6}$ units.

It is formed when iron oxidizes slowly in the presence of water; the predominant phase in the rust being γ-FeOOH. For example, X-ray diffraction patterns of the yellowish rust formed on iron placed on the bottom of a flask filled with distilled water and exposed to the air; the thin patches of yellowish rust found in drums, and inside tubes after draining a boiler; and the yellowish skin seen on steel rails immediately after a rain; all would show γ-FeOOH to be the main constituent.

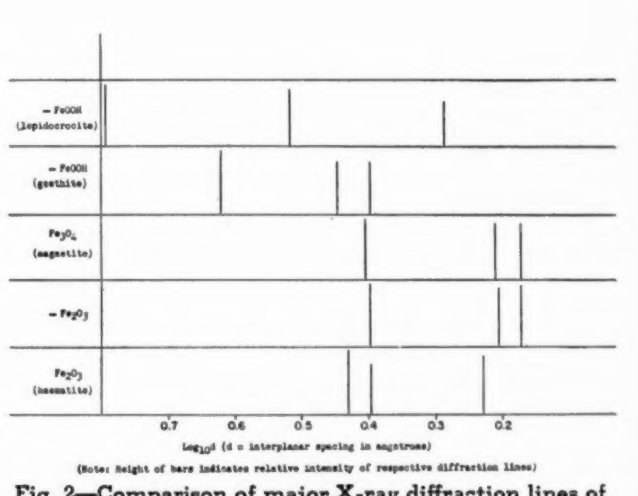

Fig. 2—Comparison of major X-ray diffraction lines of various iron oxides and oxide hydrates

This oxide loses a molecule of water readily by aging, drying or moderate heating, and complicated structural changes occur which produce radically different oxides. These changes will be described under the appropriate heading.

4. α-Ferric oxide hydrate, α-FeOOH (goethite). This oxide is formed under special conditions when $Fe(OH)_2$ or ferrous salts are hydrolyzed and oxidized, when solutions of ferric salts are heated, and when α-FeOOH is aged. It has the same crystal structure, orthorhombic, as γ-FeOOH, but somewhat different lattice parameters: $a = 4.64$, $b = 10.0$ and $c = 3.03$ angstrom units. The main diffraction lines are given in Fig. 2. The magnetic susceptibility is the same as that for γ-FeOOH.

Of the methods for preparing α-FeOOH, the oxidation of dilute ferrous chloride at room temperature is the most common. Two characteristics that distinguish goethite from lepidocrocite are (a) goethite results only from

aging $Fe(OH)_3$, and (*b*) goethite yields only α-Fe_2O_3 (paramagnetic) when it is dehydrated, whereas lepidocrocite yields γ-Fe_2O_3 (ferromagnetic) or goethite, depending upon conditions, when it is dehydrated. These reactions will be discussed under the respective anhydrous oxides.

In so far as the corrosion of iron is concerned, there is very little information in the literature concerning the conditions favoring the formation of goethite. Generally, it is found associated with lepidocrocite, but in minor quantities. In the discussion of $Fe(OH)_2$ it was stated that freshly prepared $Fe(OH)_2$ oxidizes to goethite in neutral or slightly acid solutions. This suggests that where there is plentiful oxygen, to maintain a high rate of oxidation, the formation of goethite is favored. Also, in atmospheric corrosion, where the corrosion product is likely to contain hydrolyzable ferric salts, goethite may result.

5. β-FERRIC OXIDE HYDRATE, β-FEOOH. When fairly dilute solutions of ferric chloride hydrolyze, a yellowish precipitate is produced [18]. It belongs to the orthorhombic system, similar to α and γ forms, with lattice constants $a = 5.28$, $b = 10.24$ and $c = 3.34$ angstrom units. Prior to the investigation cited, it was believed that the hydrolytic product of ferric chloride was a basic chloride. Weiser and Milligan found, however, that the Fe:Cl ratio may vary widely with no apparent change in the diffraction pattern. This suggested that the chloride ion is not an integral part of the FeOOH lattice, merely being adsorbed and serving to stabilize the lattice.

There is no mention in the literature of β-FeOOH as a corrosion product. It is possible, however, that further investigation of the corrosion products formed on ferrous materials will reveal the phases which have been reported as *basic* chlorides to be β-FeOOH, the chloride merely being adsorbed.

6. FERROUS-FERRIC OXIDE, Fe_3O_4 (MAGNETITE).[3] This oxide represents an intermediate state of oxidation between ferrous compounds and the fully oxidized, most stable oxide, α-Fe_2O_3. X-ray diffraction studies [19, 20] show the unit cell to be cubic, consisting of eight molecules of Fe_3O_4, and the lattice points to be occupied by Fe^{++}, Fe^{+++} and $O^{=}$ ions in a complicated manner. The lattice parameters are $a = b = c = 8.38$ angstrom units. The characteristics that distinguish it most strongly from the other oxides are the black color, insolubility in water, difficult solubility in acids, and a high magnetic susceptibility $\chi = +0.2$ unit (approx.), which places it in the ferromagnetic class. Another property, inherent in its crystal structure, is that it belongs to a class of compounds known as *spinels*, which have the general formula $M''O \cdot M_2'''O_3$, M'' being a divalent and M''' a trivalent ion. The significance of spinel structures in high-temperature corrosion has been discussed elsewhere.

Ferrous-ferric oxide is produced in the laboratory in a number of ways, the simplest being (*a*) slow oxidation of hot, alkaline $Fe(OH)_2$; (*b*) the oxidation of iron by air or steam between 1000 and 1500 F, the product usually containing appreciable amounts of FeO; (*c*) the reduction of Fe_2O_3 by hydrogen, at about 500 F; and (*d*) the oxidation of iron carbonyl in a controlled supply of air. The last two methods give a product that has very close to the theoretical composition.

Ferrous-ferric oxide generally will be found to a certain extent when iron is corroded by water, humid atmospheres, and hot gases and vapors. A low rate of oxidation favors the formation of Fe_3O_4. For example, when the dissolved oxygen concentration is low the rust formed by aqueous corrosion will consist mainly of Fe_3O_4. The oxidation of iron at high temperatures by steam, or an atmosphere in which the partial pressure of oxygen is low, yields a scale rich in Fe_3O_4. These conditions, however, are subject to strict limitations, depending upon the temperature, time of contact and concentration of other substances in the liquid or gas.

Source of Fe_3O_4 in Boilers

The presence of relatively large amounts of Fe_3O_4 in high-pressure boilers occasionally has been of some concern to operators. Suspended Fe_3O_4 in the boiler water may bake onto steaming surfaces as a hard, adherent sludge and cause overheating of the metal. Another difficulty ascribed to such deposits is the chemical attack of the metal which may occur as the result of the concentration of boiler water salts between the metal and the sludge.

The source of Fe_3O_4 in boilers has occasionally been attributed to circulation, whereby steaming surfaces receive insufficient water and the iron-steam reaction takes place producing Fe_3O_4 and hydrogen. Subsequent quenching by slugs of boiler water may detach the oxide and carry it in suspension in the boiler water. In a few cases this may have been, but a recent investigation [15], mentioned previously, has demonstrated that corrosion of preboiler equipment of high-pressure, low makeup systems is a source of considerable iron oxide in the boiler. It is thought that ferrous hydroxide is formed progressively in the feedwater, from the hotwell to the boiler, and that the progressive increase in temperature causes the $Fe(OH)_2$ to decompose according to equation (3).

7. α-FERRIC OXIDE, α-Fe_2O_3 (HAEMATITE). This is the most stable of all the iron oxides, being the form to which the others tend to revert under oxidizing conditions. It is reddish brown in color, insoluble in water and paramagnetic, $\chi = +20 \times 10^{-6}$ units. It crystallizes in the rhombohedral system, the parameters being $a = b = c = 5.42$ angstroms (axial angle—55° 17′), and is identical with the mineral haematite.

The *alpha* oxide is produced by any of the following reactions:

(*a*) Decomposition of solid $FeCl_3$ or $Fe_2(SO_4)_3$ in air at 1000 to 1500 F.
(*b*) Dehydration of $Fe(OH)_3$ in air at 500 to 1000 F.
(*c*) Oxidation of Fe_3O_4 in oxygen at 1000 to 1500 F.
(*d*) Dehydration of α-FeOOH (goethite) in a *closed* tube, at 275 F.
(*e*) Dehydration of γ-FeOOH (lepidocrocite) in a *closed* tube, at 465 F.
(*f*) Dehydration of γ-FeOOH in an *open* tube, at 700 F.
(*g*) Heating of γ-Fe_2O_3 in a *closed* tube, in presence of water vapor, at 275 F.
(*h*) Heating γ-Fe_2O_3 in an *open* tube, in air or oxygen at 700 F.

[3] Fe_3O_4 frequently is referred to as "magnetic iron oxide" because of its high magnetic susceptibility. However, since there is a strongly magnetic form of Fe_2O_3, it is advisable only to use the names given above when referring to Fe_3O_4.

Reactions (*d*) to (*h*) have been studied extensively by Welo and Baudisch [16, 21, 22]. The transformations of the *gamma* forms to the *alpha* form are irreversible, and the differences in behavior in closed and open tubes depend in some way upon the presence of water vapor in the former. For example, reaction (*e*), in a closed tube, is believed to occur in the following steps:

$$\gamma\text{-FeOOH} \rightarrow \alpha\text{-FeOOH} \rightarrow \alpha\text{-Fe}_2\text{O}_3 \qquad (4)$$

no γ-Fe_2O_3 being found at any stage of the transformation. In an open tube, reaction (f), γ-Fe_2O_3 occurs as an intermediate product:

$$\gamma\text{-FeOOH} \rightarrow \gamma\text{-Fe}_2\text{O}_3 \rightarrow \alpha\text{-Fe}_2\text{O}_3 \qquad (5)$$

Because of the complex relations noted above, it is difficult to state the conditions under which α-Fe_2O_3 will be an end-product in the aqueous corrosion of iron; time, temperature, oxygen pressure and aqueous tension being important variables. In the case of low-temperature corrosion in air, α-Fe_2O_3 begins to form on iron at about 400 F. Below this temperature the oxide is predominantly γ-Fe_2O_3.

8. γ-Ferric oxide, γ-Fe_2O_3. This form resembles the *alpha* form in color, insolubility and chemical composition. The resemblance goes no further, however, since the crystal structure and magnetic susceptibility are entirely different. In these respects, it is nearly indistinguishable from Fe_3O_4. The structure is cubic, with parameters $a = b = c = 8.32$ angstroms. Comparison of the diffraction lines for γ-Fe_2O_3 and Fe_3O_4 shows them to be nearly identical, high-precision cameras, careful technique and close attention to inherent errors in the measurement of the diffractions being required to resolve the subtle differences in the patterns. The outstanding characteristic of γ-Fe_2O_3 is that it has the same magnetic susceptibility as Fe_3O_4 $\chi = +0.2$ (approx.). Because of its high susceptibility γ-Fe_2O_3 often is referred to as "ferromagnetic ferric oxide."

One of the methods for the formation of γ-Fe_2O_3 is to oxidize Fe_3O_4 under certain conditions, the color change from black to red being easily followed. The mechanism of this change has been the subject of considerable study to account for the fact that although four atoms of oxygen enter the unit cell of Fe_3O_4, which consists of eight molecules of Fe_3O_4, no change occurs in the crystal structure or magnetic susceptibility.

The important reactions leading to the formation of γ-Fe_2O_3 are as follows:

(*i*) Oxidation of Fe_3O_4 in air or oxygen at 425 F; cf. reaction (*c*).

(*j*) Dehydration of γ-FeOOH in an open tube at 465 F; cf. reaction (*f*).

(*k*) Dehydration of γ-FeOOH in a closed tube at 275 F; cf. reaction (*e*).

It is difficult at the present time to state with any certainty the conditions necessary in the corrosion of iron for the formation of γ-Fe_2O_3. Reactions (*j*) and (*k*) suggest that where lepidocrocite is a constituent of rust, dehydration may lead to γ-Fe_2O_3. It is to be noted also that the temperatures required for the transformations of γ-FeOOH to γ-Fe_2O_3 are lower than for the transformations to α-Fe_2O_3.

Conclusions

Although there have been sporadic efforts to relate the properties of corrosion products to the mechanism and rate of corrosion, especially in the field of high-temperature corrosion, a great deal of research remains to be done. The problem is not an easy one as attested by the complex relations even among the simpler oxides of iron, and the complicated nature of the corrosion products that are formed on metals under relatively ordinary conditions. To effect the best results, data must be obtained from two sources: the field, where the variables are usually uncontrolled and lead to complex and heterogeneous corrosion products; and the laboratory where conditions may be controlled, and the properties of the individual phases may be studied separately. No serious corrosion investigation should be considered complete until every possible test on the corrosion products has been made. To dismiss a corrosion product from further consideration by the simple expedient of assuming it to be a certain oxide may be to overlook an important clue to the mechanism of attack. Sometimes wishful thinking leads to erroneous conclusions. Recently in the writer's experience a corrosion product from a high-pressure boiler was reported to be "the high-temperature cubic modification of Fe_2O_3" meaning, apparently, γ-Fe_2O_3. Subsequent examination of the product by refined X-ray diffraction technique revealed it to consist of metallic copper and Fe_3O_4; there being neither evidence of γ-Fe_2O_3 nor theoretical justification for its presence in the boiler. Until corrosion investigators adopt a critical attitude toward corrosion products, and make it an invariable rule to report as much of their chemical and physical properties as possible, little can be done to clarify or explain many rather ordinary corrosion phenomena that at the present time are puzzling.

Fundamental laboratory studies clearly are needed to determine the methods of formation, solubility, range of stability and thermodynamic properties of a wide variety of the constituents found in corrosion products. One of the first problems for the physical chemist, as has already been noted, is the determination of the properties of $Fe(OH)_2$. The data at present are inconsistent and incomplete.

In so far as analytical techniques are concerned, the chemist has available X-ray diffraction [23] or electron diffraction [24] methods for determining exactly the phase present in as little as one milligrain of sample. For the determination of the anions and cations separately, the micro-chemical and polarographic methods are extremely useful. It is apparent, therefore, that where the amount of corrosion product is too small for a gross chemical analysis, important information can be obtained by the methods described above.

In conclusion, it is recommended that wherever possible the following data should be obtained on all corrosion products:

(1) Chemical analysis to determine the anions and cations present.

(2) Solubility in water, noting if the water-soluble fraction hydrolyzes when it is heated, and if an acid, neutral or alkaline condition occurs.

(3) The change of weight at 210 F and at about 1500 F, noting any characteristic odors evolved when heated at the higher temperature.

(4) Magnetic susceptibility, which need be only a qualitative test with a permanent magnet.

(5) The polarizing characteristics under crossed nicols if the material is translucent or transparent.

(6) X-ray or electron diffraction analysis of the gross material and of each constituent mechanically and magnetically separable. If the material is layered, or otherwise noticeably heterogeneous, each phase should be analyzed separately.

In some cases there will not be sufficient sample to perform each of these operations, and common sense will eliminate some of them, but in every case an X-ray diffraction analysis should be made.

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EQUIPMENT SALES

as reported by equipment manufacturers to the Department of Commerce, Bureau of the Census

Boiler Sales

Stationary Power Boilers

	1946 Water Tube		1945 Water Tube		1946 Fire Tube		1945 Fire Tube	
	No.	Sq Ft*	No.	Sq Ft*	No.	Sq Ft	No.	Sq Ft
Jan.	173	1,110,924	96‡	534,669‡	113	154,064	50	60,710
Feb.	197	1,262,520	101‡	481,726‡	126	171,100	75	99,815
Mar.	171	1,356,608	134‡	759,214‡	123	180,532	77	87,266
Jan.–Mar., incl.	541	3,730,052	331	1,775,609	362	505,696	202	247,781

* Includes water wall heating surface. ‡ Revised.

Total steam generating capacity of water tube boilers during this period Jan.–Mar. (incl.), 1946, 20,100,000; in 1945, 19,227,000.

Marine Boiler Sales

	1946 Water Tube		1945 Water Tube		1946 Scotch		1945 Scotch	
	No.	Sq Ft	No.	Sq Ft	No.	Sq Ft	No.	Sq Ft
Jan.	2	11,276	335‡	1,400,090‡	1	590	6	1,073
Feb.	–	—	34	178,726	–	—	5	1,186
Mar.	–	—	49‡	193,124‡	4	1,706	10	7,685
Jan.–Mar., incl.	2	11,276	118	1,771,940	5	2,296	21	9,944

‡ Revised.

Mechanical Stoker Sales†

	1946 Water Tube		1945 Water Tube		1946 Fire Tube		1945 Fire Tube	
	No.	Hp	No.	Hp	No.	Hp	No.	Hp
Jan.	61	35,757	42‡	18,990‡	185	23,625	187	25,299‡
Feb.	73	41,362	57‡	22,510‡	175	27,708	162	20,565
Mar.	93	45,493	87‡	32,451‡	182	28,080	233	32,447
Jan.–Mar., incl.	227	122,712	186	73,951	542	79,413	583	78,311

† Capacity over 300 lb of coal per hour. ‡ Revised.

Mixtures of Bituminous Coal and Anthracite

The Annual Report of the U. S. Bureau of Mines, just issued, dealing with research and technologic work on coal, makes the following observations on burning mixtures of bituminous coal and anthracite.

Studies and tests along this line were instigated by the Solid Fuels Administration for War to alleviate the general fuel shortage in eastern states last year, and to find increased markets for anthracite fines.

The burning of barley anthracite and bituminous slack on underfeed stokers showed that an addition of about 15 per cent of anthracite was usually enough to reduce caking. Increased percentages of anthracite decreased the pressure drop through the fuel bed, decreased the manual attention to the fuel bed, and decreased the smoke; but increased the fly ash and refuse; although, in general, the clinkering conditions were improved.

The load-carrying capacity of the stoker was affected by the relative proportions, compositions and properties of the anthracite and bituminous coal present, although the efficiencies obtained on single-retort stokers with a reasonable range of anthracite admixtures were about the same as with straight bituminous coal.

The studies, made with the cooperation of numerous industrial and government-owned plants, resulted in the use, in many cases, of mixtures employing from 30 to 50 per cent anthracite.

The Bituminous Coal Agreement

FOLLOWING are the more important terms of the agreement between Secretary of the Interior Krug, acting as Coal Mines Administrator, and the United Mine Workers of America, upon which the strike was settled, following a loss in production of 76,000,000 tons of bituminous coal. These terms supplement the National Bituminous Coal Wage Agreement of April 1945.

Wages

In effect, the basic hourly rate is increased $18^1/_2$ cents. All mine workers, whether employed by the day, tonnage or footage rate, will receive $1.85 per day in addition to that provided for in the contract which expired March 31, 1946.

On a weekly basis this means that a miner will receive $59.25 for 5 days' work and $75.25 for 6 days' work, as compared with the previous wages of $50 for 5 days and $63.50 for 6 days, figured on a 9-hr portal-to-portal work day.

An annual vacation period shall be the rule of the industry. This year the vacation period will be from June 29 to July 8, with a vacation payment of $100. Men required to work during this period shall be given equivalent vacations at a later agreed date.

Welfare and Loss of Wages

This fund will be financed by the operating managers by payment of 5 cents per ton of coal produced; the fund to be administered by three trustees, one appointed by the Coal Mines Administrator, one by the union, and the third chosen by the other two. The fund is to be used for payments to miners and their dependents with respect to wage loss not otherwise compensated adequately under federal or state law. This will include sickness, disability, death, retirement and other welfare purposes.

Medical and Hospital Fund

This, which will be accumulated from wage deductions as authorized by the union, will be administered by trustees appointed by the President of the United Mine Workers. It will be used to provide for medical, hospital and related services for miners and their dependents, and, at the discretion of the trustees for variations and adjustments within the framework of the union's organization.

The trustees of the two funds are to cooperate in making them complementary.

The Coal Mines Administrator will also direct each operating manager to provide employees with protection of workmen's compensation and occupational disease laws, whether compulsory or elective within that state.

Mine Safety Program

Within 30 days after the date of the agreement, the U. S. Bureau of Mines, after consultation with the United Mine Workers, is to issue a code of standards and rules on safety conditions and practices. The code will be put in effect by the Coal Mines Administrator, and Bureau of Mines inspectors will make periodic investigations and report on violations. In cases of violation the Coal Mines Administrator will take appropriate action, which may include disciplining or replacing the operating manager.

At each mine there will also be a Mine Safety Committee, selected by the local union.

Supervisors

With respect to questions affecting employment and bargaining status of foremen, supervisors, technical and clerical workers employed in the bituminous mining industry, the Coal Mines Administrator will be guided by decisions and procedure laid down by the National Labor Relations Board.

New Station for New Jersey System

Construction will be started shortly on a new steam-electric generating station for the Public Service Electric and Gas Company at Sewaren, N. J. The initial installation will include two 100,000-kw turbine-generators supplied by two 850,000-lb per hr Combustion Engineering boilers designed to deliver steam at 1500 psi, 1050 F at the turbine throttle. These will be tangentially fired with vertically adjustable burners for burning either pulverized coal or oil and the furnace bottoms will be of the continuous slag discharge type.

The turbine-generators, one General Electric and the other Westinghouse, will be of the tandem-compound, condensing type, condensing water being taken from the Arthur Kill on a bank of which the plant will be located.

It is expected that the plant will be ready to carry system load in the fall of 1948.

Electric Output Shows Decrease

Electric energy produced for public use in April 1946 totaled 17,480,827,000 kwhr, a decrease of 6.2 per cent compared with April 1945, while the combined production of utilities and industrial establishments showed a decrease of 6.8 per cent, according to figures issued by the Federal Power Commission. Production by water power was 38.2 per cent of the utility output.

For the twelve months ending April 30, 1946, the total utility output was 215,844,506,000 kwhr which represented a decrease of 5.5 per cent from the preceding twelve-month period.

The capacity of generating plants in utility service, as of April 30, 1946, was 50,204,823 kw and the total industrial generating capacity is given as 12,761,344 kw.

Atomic Energy Discussed at Westinghouse Centennial

Several speakers at the Forum on May 16–17, celebrating the one hundredth anniversary of George Westinghouse's birth, dealt with the subject of atomic energy and its control.

Dr. Enrico Fermi, professor of physics at the University of Chicago, observed that the fission energy of uranium is roughly 3 million times that of an equal amount of coal; and if scientists ever succeed in developing a practical method of utilizing the energy stored up in uranium, future generations will not have to worry much about our dwindling supplies of coal. The energy value of one pound of uranium is so great, he pointed out, that even an enormous increase in cost of this material may not interfere with its economical use as a source of power. Three million tons of coal, equivalent in energy to one ton of uranium, cost about eight million dollars. Consequently, as far as the cost of raw materials is concerned, uranium and coal would become equivalent with uranium costing $4000 per pound. Before the war uranium cost only about $2 a pound.

He stated that at Hanford the atomic piles produced energy comparable to the largest hydroelectric plants, but as this energy is there produced at such a low temperature level it is at present of no practical value. However, he believed it possible to produce this energy at any desired temperature level and foresaw that in 20 or 30 years large atomic energy installations might supply our power requirements, with due consideration being given to the economics involved, such as the large amount of shielding necessary.

Dr. J. Robert Oppenheimer, professor of physics at the University of California was of the opinion that progress toward attaining the beneficient factors to be derived from atomic energy were likely to be retarded by suspicions on the part of other nations. He therefore proposed an international convention restricted to the field of atomic energy.

Steel Patent Dedicated to Public Use

Patent rights to the use of "stabilized" steel composition designed to meet requirements of increasingly high temperatures in steam lines of power plants, and in the chemical industry, have been dedicated, on a royalty-free basis, to public use by the U. S. Steel Corporation and the Carnegie Steel Corporation. This patent (No. 2,359,043) which emerged from the research laboratories of these companies, was issued to Dr. Marcus A. Grossman, director of research, and Dr. R. F. Miller, development engineer. It relates to the use of a grade of steel particularly resistant to graphitization when subjected to stress in the temperature range from 800 to 1100 F; and has a carbon-molybdenum-chromium composition.

In describing the steel, the statement is made that formerly plain carbon-molybdenum steel was considered safe for use in stress at temperatures up to about 1100 F, since it was known to have adequate creep strength within this range; but

recently it has been found that with prolonged use at elevated temperatures the carbon in the steel graphitizes so as to produce planes of weakness. It is believed that this effect might prevail at temperatures as low as 850 F over sufficient time, and it has been found definitely present at temperatures above 900 F.

At first, where conditions required a change from plain carbon-molybdenum steel, it was common to use a more expensive material containing one per cent or more of chromium; but it was found that chromium in such quantities not only increased the cost but also detracted somewhat from the creep strength. Use of the small amount of chromium in the Grossman-Miller invention produces a steel which is both practical and economical, since the small additional cost is offset by longer service life. It is stated that a further advantage is that the amount of chromium used does not materially affect creep strength. Also, since the small amount of chromium does not make the steel air-hardening, it can be handled and processed in the usual manner.

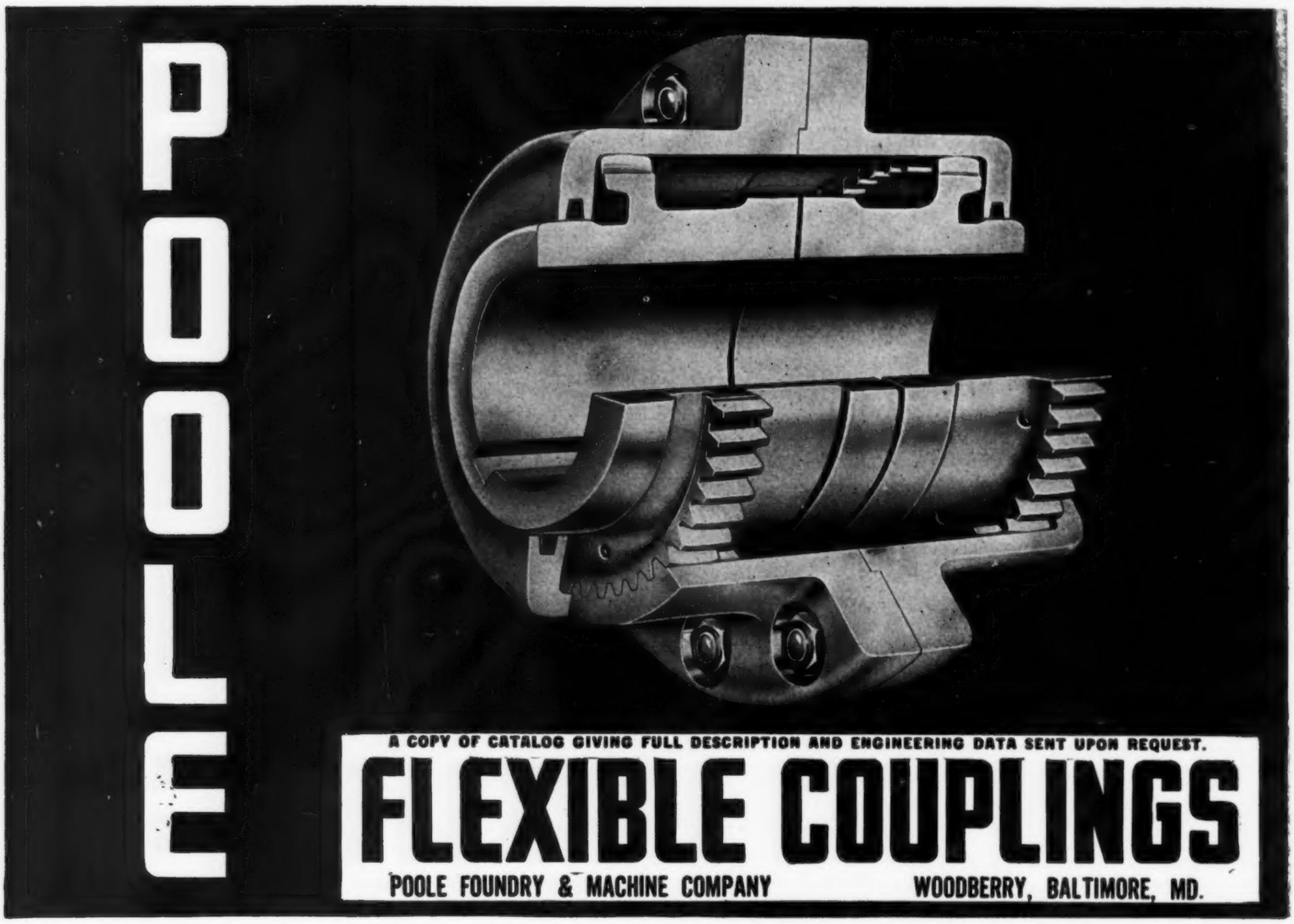
The steel embraced in the patent now made available to public use is of the pearlitic, non-air-hardening type containing from 0.08 to 0.20 per cent carbon, 0.45 to 0.65 per cent molybdenum and from 0.15 to less than 1 per cent chromium, which is proportioned with respect to the carbon content to fix substantially all the carbon in the form of carbide. This is stable within the defined temperature range. According to Dr. Grossman, this steel is not only more stable from the standpoint of graphitization and spheroidization, but it also has a strength equivalent to that of carbon-molybdenum steel previously used.

Incorporates in New York

Brown Boveri Corporation has recently been incorporated under the laws of the State of New York, as an affiliate of Brown Boveri & Company, Ltd., of Baden, Switzerland. The new company, with Paul R. Sidler as president, will intensify and expand the activities carried on for the last fifteen years by the New York Office of the Swiss Company in the dissemination of data and information on Brown Boveri products and their applications. These products include voltage regulators, mercury arc rectifiers, circuit-breakers, relays, turbine-blowers, gas-turbine-driven compressors for oil cracking plants, exhaust gas-turbine-driven superchargers, the Velox boiler, steam-turbine generators and control equipment.

New Company Formed

Three former executives of The Permutit Company, S. B. Applebaum and H. L. Tiger, vice presidents, and Norman E. Brice, mechanical engineer, have organized a new company under the name of Liquid Conditioning Corporation to carry on business in the field of water conditioning and the conditioning of other fluids used in industry. Present offices are at 423 West 126 Street, New York City, and arrangements are being made for construction of a plant at Linden, N. J.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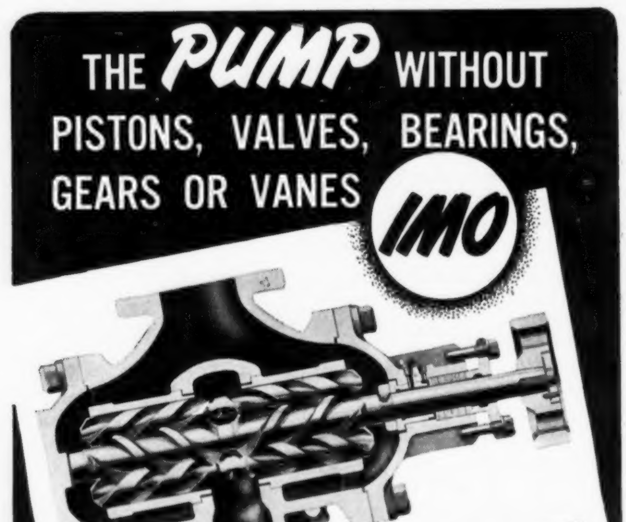
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B. J. Cross to Manage CEC Development and Research

Bertram J. Cross has been designated to take over management of the Development and Research Department of Combustion Engineering Company, succeeding the late Henry Kreisinger with whom he had been closely associated for over 25 yr.

A graduate of Colorado College in 1913, Mr. Cross spent the next few years in mining operations in the West, and in 1917 joined the staff of the U. S. Bureau of Mines where he engaged in fuels research. He came to Combustion Engineering Company in 1920 and was identified with the early applications of pulverized coal to power boilers, notably those at Oneida Street and Lakeside Stations, Milwaukee. With the exception of $2^1/_2$ yr spent away from the company in the early thirties, he has given his entire time to research and development, involving field work in testing, temperature measurements, boiler water studies and fuel-burning problems.

Mr. Cross is a member of several important committees of the A.S.M.E. including Boiler Feedwater Studies, the Boiler Test Code and Fuels, and has been the author of numerous papers before that society and other engineering bodies.

Fall Meetings

The Annual Meeting of the American Welding Society will be held in New York on October 24 and immediately adjourn, without transaction of business, to reassemble in Atlantic City on November 17 to 22 in conjunction with the National Metal Congress.

The Seventh Annual Water Conference of the Engineers' Society of Western Pennsylvania is scheduled for October 28 to 30 at the William Penn Hotel, Pittsburgh.

A Joint Meeting of the A.S.M.E. Fuels Division and the Coal Division of the A.I.M.E. will be held in Philadelphia on October 24 to 26.

The regular Fall Meeting of the A.S.M.E. will be held in Boston, on September 30 to October 2.

Personals

Harold P. Richmond, formerly general superintendent of operations for the Jersey Central Power & Light Company, has joined the New York Office of Allis-Chalmers Mfg. Company as central station representative specializing in steam and gas turbine matters.

J. R. McDermet, associated for many years with Elliott Company, has opened an office as consulting engineer at 18th and Chestnut Streets, Philadelphia. He will specialize on water purification, corrosion control and allied subjects.

James W. Parker, president of The Detroit Edison Company, was recently elected president of the Association of Edison Electric Illuminating Companies.

W. A. Ramsay, head of W. A. Ramsay, Ltd., long-established engineering and industrial sales organization of Honolulu, Hawaii, recently retired from active participation in the operations of his company upon reaching the age of 70.

A. L. Anderson has been appointed assistant fuel service engineer of The Chesapeake & Ohio Railway Company with headquarters in the General Motors Building, Detroit. He succeeds A. D. Muldoon.

J. W. Barker has resigned as dean of the School of Engineering at Columbia University to become president of the Research Corporation, New York.

Manufacturers' Appointments

De Laval Steam Turbine Company has appointed James P. Stewart as special representative for centrifugal blowers and compressors. He was for a number of years connected with the Elliott Company and later was assistant general manager of B-W Superchargers, Inc. His headquarters will be in Trenton, N. J.

The Dampney Company of America, Hyde Park, Mass., has appointed Kenneth E. Green to the sales staff of its Chicago Office and William T. Campbell to its Philadelphia Office.

Recent appointments by the Elliott Company, Jeannette, Pa., include J. N. McClure as manager of its Petroleum Division with headquarters in Houston, Tex.; C. F. McGinnis as Kansas City district manager; and J. E. Walsh as manager of the Houston District Office.

Permutit Company, New York, has appointed H. L. Bechner technical manager and A. D. Way chief mechanical engineer.

The Terry Steam Turbine Company has appointed Glen C. Barnaby district representative for the San Francisco territory with offices in the Rialto Bldg., San Francisco.

L. J. Wing Mfg. Company, New York, has appointed the Harang Engineering Company of San Francisco as its representative in Northern California. Mr. Harang, head of that firm, recently returned from service as an officer in the Navy.

Engineering Committee Preparing Industrial Disarmament Program for Japan

At the request of the State and War Departments, the National Engineers Committee of the Engineers Joint Council, representing the five national engineering societies in the United States, is preparing a program to eliminate the industrial war potential of Japan.

According to Col. C. S. Proctor, Chairman of the Committee, there are sixteen subcommittees working on the report. These are made up of American engineering and technological specialists in the various fields involved. The program will deal with the limitation of metal products, chemicals, power, mineral resources and other items of war-making potential.

Plan Similar to That Adopted for Germany

It will parallel in many respects similar recommendations submitted in September 1945 and recently accepted by the Allied Control Council for Germany. The German plan rigidly restricts or entirely prohibits industry adaptable to war purposes, but curbs are selective in order to provide for the normal requirements of that country's peacetime economy and to avoid a disastrous economic vacuum. The Allied Control Council has also approved a law providing for continuing control of scientific research in Germany in order to prevent its utilization for purposes of aggression and to direct permitted research along peaceful lines.

The Control Council's program leaves Germany a total industrial capacity with which to produce approximately 75 per cent of her 1936 industrial output (figured at 1936 prices), or perhaps between one-third and one-fourth of her war production level. However, the 75 per cent is not evenly distributed through the German economy.

In the various basic industrial fields essential to any war machine, the Council left only slightly more than half the 1936 capacity; whereas for those industrial activities that cannot be easily distorted to a war effort, the plan leaves sufficient capacity to produce an estimated average of 95 per cent of the 1936 volume. For instance, Germany's metallurgical and metal-working activities, will be geared to the limits of a steel production of 5,800,000 ingot tons annually from 7,500,000 tons of capacity. This is in contrast to a war production of 28,000,000 tons of ingots annually. Some industrial fields are not limited at all in order to provide potential expansion in harmless pursuits for workers forcibly displaced by curtailment of Germany's traditionally large heavy industry production.

Coal Production to Be Speeded

On the other hand, coal production will be given assistance by the Council, with a minimum goal set at 155 million tons annually by 1949. This includes about 45 million tons for export.

The plan for Japan is expected to be completed this month.

NEW CATALOGS AND BULLETINS

Any of these publications will be sent on request

Boilers, Fuel Burning and Related Equipment

This is a 12-page condensed catalog of regular products for stationary power plants, designed and manufactured by Combustion Engineering Company. Each class of equipment is summarized and illustrations are included of typical units in each class group of boilers ranging from 1000 lb per hr up to 1,000,000 lb per hr capacity, with steam pressures up to 1800 psi and 955 F total steam temperature. Seven types of stokers are included as well as the bowl mill, horizontal and tangential burners for pulverized coal, superheaters, economizers and air heaters of both the plate and tubular types.

Boiler Feed Control

Bulletin 453, published by Northern Equipment Company describes the boiler feedwater control with Copes "Flowmatic" regulators at the new boiler plant of the New York Navy Yard (Brooklyn). This plant contains six, 165,000-lb per hr, 400-psi, 725-F steam-generating units supplying three turbine-generators and various yard services under wide variations in steam demand.

Condenser Injector

This bulletin, issued by Condenser & Engineering Company, illustrates and describes the operation of the Wizard condenser injector, designed to stop leaks while the condenser continues to operate.

Fans

A new catalog, No. 430-3, has been issued by B. F. Sturtevant Company describing its line of fans for dust control, fume exhaust and materials handling. Tables of dimensions and performance are included as well as other pertinent data; including a chart showing pressure loss in round ducts.

Desuperheaters

Bulletin U-1, just issued by Elliott Company, describes its cartridge-type desuperheater. This consists of a cast-steel body with integral flanges into which is inserted a removable cartridge of copper or stainless steel. Steam is admitted through a nozzle and passes through interstices of the cartridge. The desuperheating water is injected through nozzles located at the inlet side of the cartridge and trickles down through the woven wire mesh. Desuperheating is accomplished partly by direct mixing of the steam and water and partly by the alternate wetting and heating of the cartridge wires. Automatic temperature control is applicable where desired. Tables of dimensions are included.

Electric Generator

The newly developed "Regulectric" a-c generator for use with small engine-generator sets provides general-purpose electric power at constant voltage, using a built-in voltage regulating circuit employing the principle of series-resonance. It is described in Publication 186, a two-color, four-page folder published by Electric Machinery Mfg. Co.

Protective Coatings

The Dampney Company of America has issued a new bulletin dealing with "Thur-Ma-Lox" high heat-resistant coatings, which are said to be effective on metal surfaces subjected to temperatures up to 1600 F. Among the power plant applications listed are steel stacks, breachings, furnace doors, air preheaters, gas turbine equipment and induced-draft casings, in addition to a number of industrial applications.

Refractory Concrete

A new edition of "Lumnite for Refractory Concrete" has just been published by the Atlas Lumnite Cement Company. This 24-page booklet contains basic information on materials and methods used in making refractory concrete for different temperature and insulating requirements. Illustrations show a wide range of applications.

Potentiometer-Pyrometer

A new electronic Potentiometer-Pyrometer which has no continuously moving or vibrating parts in its measuring circuit is described in Bulletin 232 of the Bailey Meter Company. This instrument records one or two temperatures on a 12-in. diameter uniformly graduated chart and indicates on a 29-in. bold scale which encircles the recording chart. It requires a 115-volt, 60 or 50 cycle, a-c power supply, and operates from a thermocouple or from any source of d-c potential which varies through at least 10 millivolts for full scale range. Conventional thermocouples are used for temperatures up to 3000 F. For temperatures above 3000 F and for moving objects above 1500 F radiation type thermocouples are used.

BOOKS

1—Marine Engineers' Handbook

EDITED BY PROF. J. M. LABBERTON

2013 pages $4^1/_2 \times 7$ $7.50

This handbook is designed by the publishers as a successor to Sterling's Marine Engineers' Handbook, once the "Bible" of the marine engineering profession. The work has been practically re-written and is as modern and up-to-date as the ships now under construction.

The handbook is a compilation of the work of sixty-three specialists under the editorship of Professor J. M. Labberton.

While principally a designer's and technical student's handbook, the operating engineer will find a considerable amount of helpful information, particularly in the section on boilers.

The field is thoroughly covered with sections on engineering fundamentals, hull design and construction, marine power generation, boilers of various types, oil firing and handling turbines, steam engines, internal combustion engines, propulsion, auxiliaries, deck machinery, heating and ventilating, electrical engineering, refrigeration, tests and ship trials. The subjects are well covered from the basic theory and equations, and amplified with design data, charts, curves, descriptions and construction details.

2—Boiler Room Questions and Answers

BY ALEX HIGGINS

139 pages $8^1/_2 \times 11$ Price $3.00

The need for a reliable and up-to-date book on boiler room practice (and of particular merit for those men who are studying for licenses or certificates as operating engineers) has been adequately met in this volume by Alex Higgins. Parts of the book have already appeared in the pages of *Power* magazine, and many illustrations of fine quality support the text.

The Question and Answer form is excellent and the 26 chapters comprise a comprehensive review of typical examination questions on the essential principles of design, construction and operation of boilers and boiler room accessories. The Answers are couched in simple terms and offer the candidate for a license an excellent example of how to handle the questions posed to him in his written examination.

3—The Modern Gas Turbine

BY R. TOM SAWYER

216 pages 6 × 9 Price $4.00

Although the fundamental principle of the gas turbine was known more than 2000 years ago, its development in recent years has been so rapid that no one in the power generation field can afford to ignore its imminent possibilities. For this reason, Mr. Sawyer's book will have particular appeal to those engineers who want to be informed as to the latest applications of the gas turbine as a supercharger and as a prime mover.

The author has compiled an authoritative treatise which outlines the earliest concepts of the gas turbine and traces its development from hot air engines built at the beginning of the eighteenth century to modern times. It covers application to supercharged diesel engines and includes chapters on The Gas Turbine in Industry; in Marine Service; and also The Gas Turbine Locomotive. Concluding chapters deal with The Exhaust Turbosupercharger on Aircraft Engines and The Gas Turbine as an Aircraft Prime Mover, including Jet Propulsion.

The book is generously illustrated and includes three pages of general references and a 10-page index.

4—Chemistry of Coal Utilization (2 volumes)

1850 pages Price $20.00

This book is in two volumes containing about 1850 pages and was sponsored by a special committee of the Division of Chemistry and Chemical Technology of the National Research Council. This committee, headed by Dr. H. H. Lowry of Carnegie Institute of Technology, consisted of forty members representing various research institutes and commercial organizations interested in coal. It arranged the subject matter into forty chapters, each dealing with one phase of the subject, and preparation of the text was assigned to twenty-nine authors, selected because of their training and experience. These authors reviewed some 15,000 pages of literature on the subject, published in ten languages. Wherever possible, digests of the original articles are incorporated and the text is well supplied with references to the original publications.

5—Applied Energy Conversion

BY B. G. A. SKROTSKI AND W. A. VOPAT

509 pages 6 × 9 Price $5.00

Despite its broad title, the text of this book deals with power plants of the steam, internal combustion, and hydro types, with considerable attention being paid to the general economic side of power production and performance. Typical equipment entering into such plants is briefly described and illustrated without going into design problems, as it is felt that these come within the province of specialists among the equipment manufacturers.

Beginning with a chapter on "Raw Energy," devoted to the classification and characteristics of coals, oil, gas and refuse fuels, the book takes up, in order, combustion calculations, methods of firing, steam-generating units, prime movers, feedwater systems, steam plant cycles and heat balance, diesel and gas engine plants, hydro power, power plant developments, general economic problems, load curves, selection of plant and equipment, and station performance and operating characteristics; also concluding chapters on specific energy problems and energy rates.

The text is written primarily for students in heat-power engineering, but it should also provide useful refresher reading for engineers already following the power plant line.

6—The Efficient Use of Fuel

PREPARED BY THE MINISTRY OF FUEL AND POWER

807 pages $8.50

This authoritative British handbook was assembled by 140 engineers, scientists and industrial associations, and is replete with information about fuels and their uses in a wide diversity of industries.

British coals and manufactured gas form the bulk of the fuels considered, and a brief chapter is devoted to oil and its utilization. To assist the reader, a complete bibliography of Fuel Research Papers is identified.

The book has an index and each of its thirty-four chapters has a short compendium in the Table of Contents.

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General and Classified Index

COMBUSTION, Volume Seventeen, July 1945 through June 1946

EDITORIALS—

ARTICLES—

AUTHORS—

REVIEW OF NEW BOOKS—

CLASSIFIED INDEX—

Auxiliaries

Boilers

Coals

Coal- and Ash-Handling Systems

Combustion

Corrosion

Fans

Feedwater

Fuels

Gas Turbines

General Practice, Developments and Trends

Heat Balance

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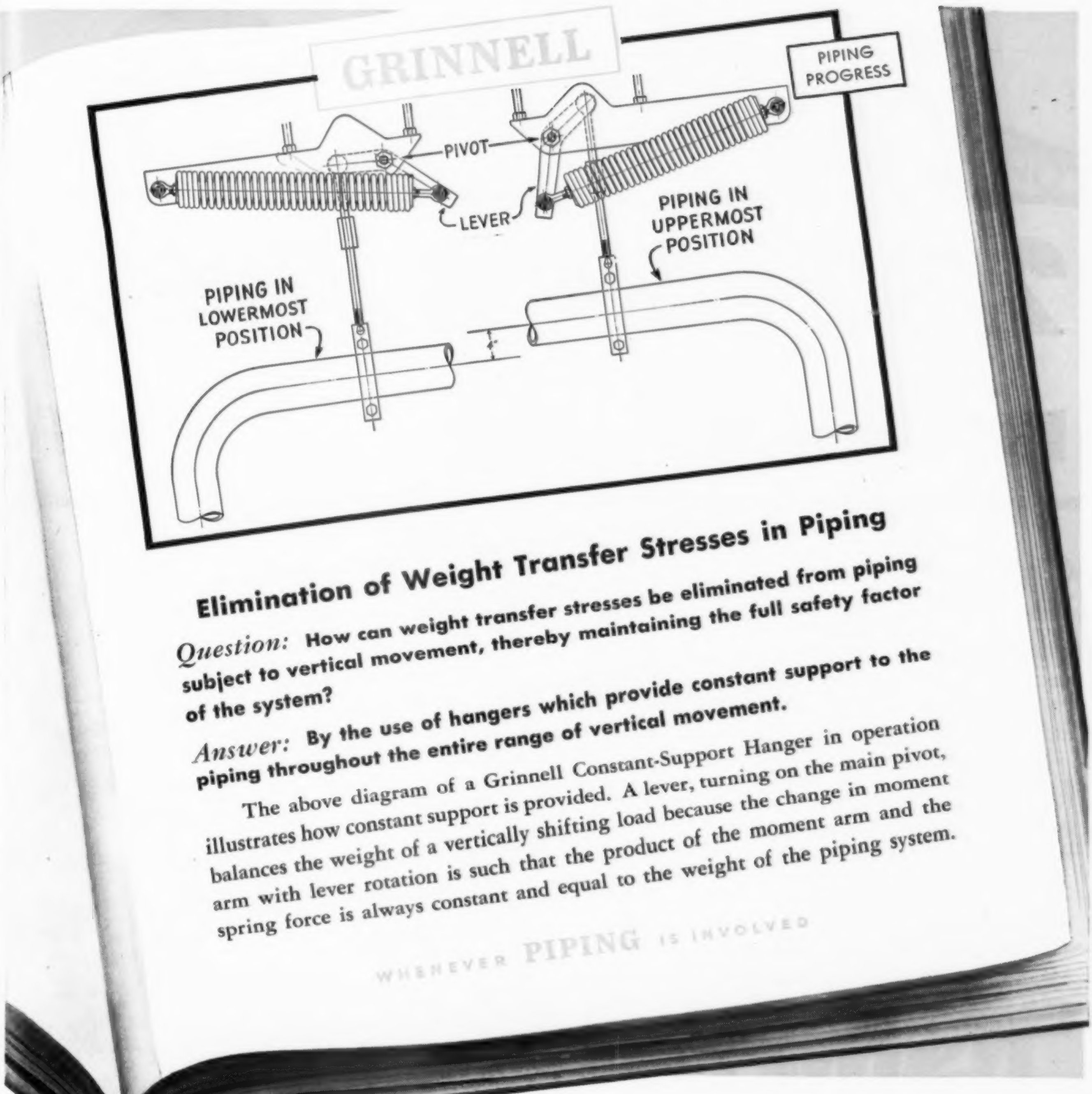
Marine Practice

Navy Tests

Pulverized Fuel



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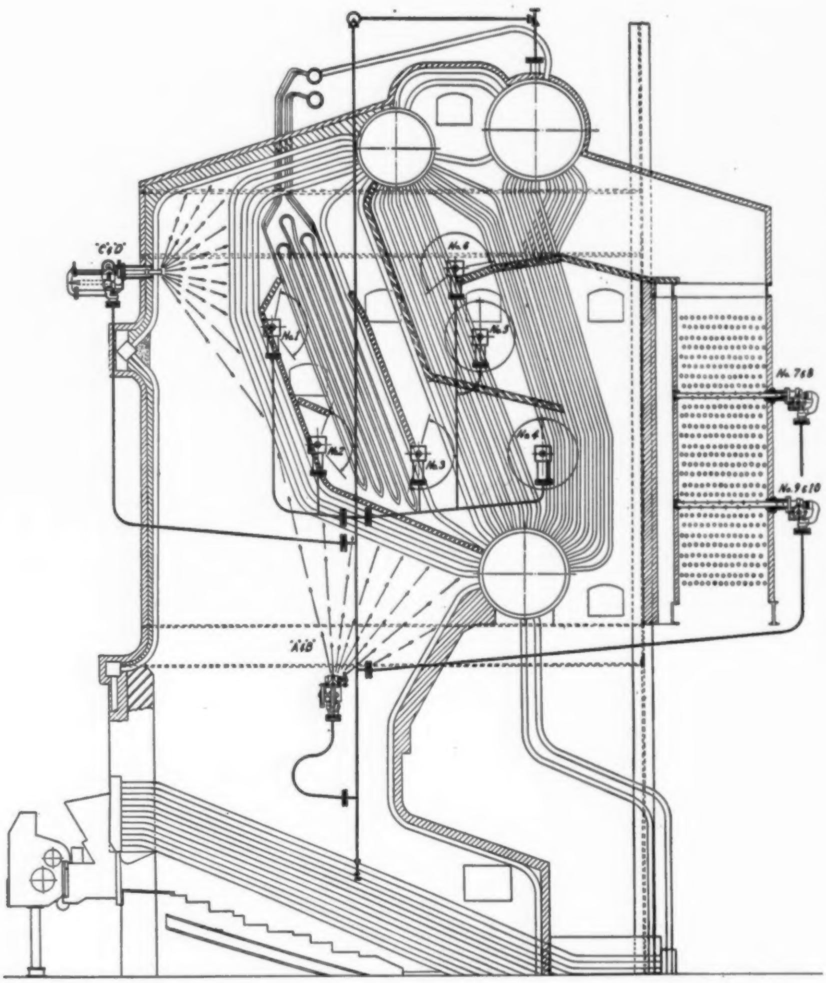

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Later in that same year Bayer Retractable Gun Type Cleaners were installed on two more duplicate boilers.

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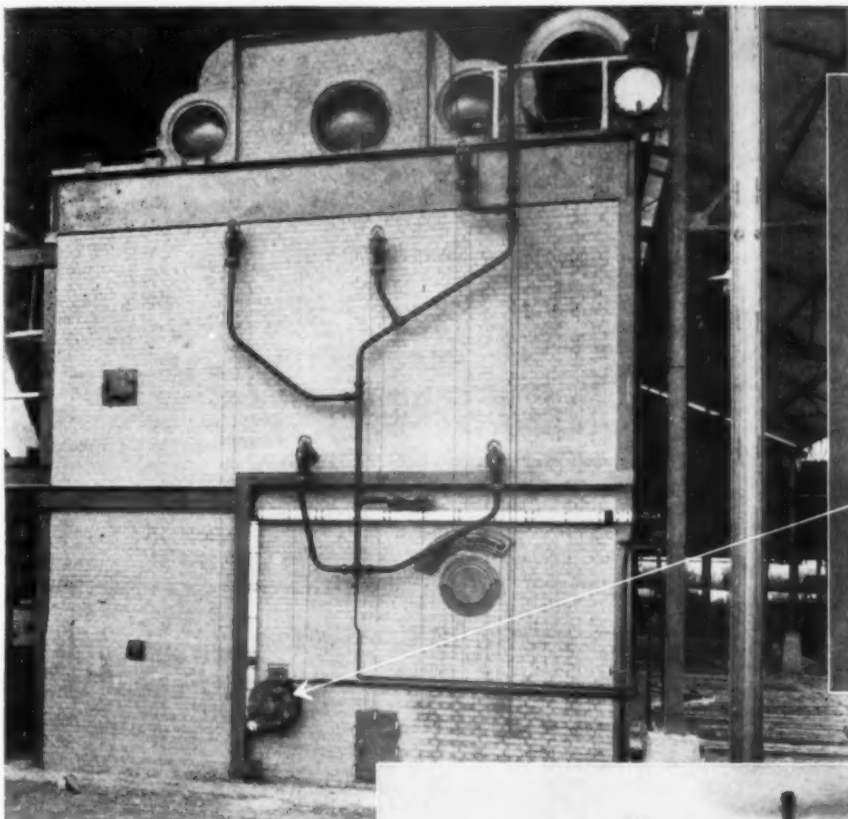
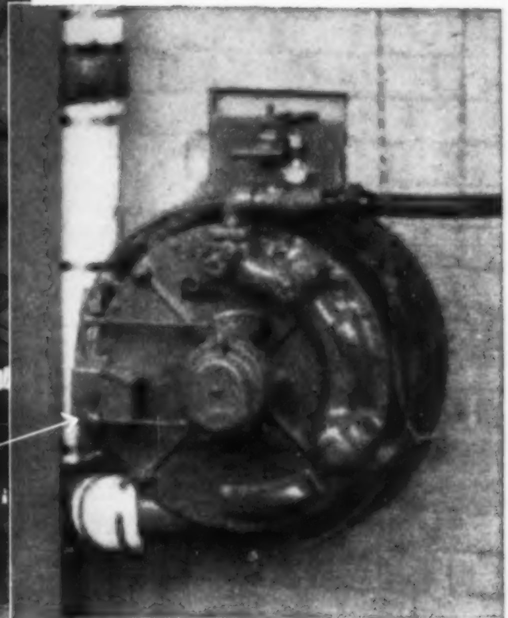




(Above) *Closeup of Wing Turbine Driven Blower showing simplicity and compactness.*

(Above) *View of one of the boilers showing the Wing Turbine Driven Forced Draft Blower. Note how neatly it is cemented into the brick boiler wall.*

(Left) *Exterior view of the Central Mercedita, in the municipality of Melena del Sur, Cuba.*

Wing Turbine Blowers at Central Mercedita

There are eight Wing Turbine Driven Forced Draft Blowers at the big sugar mill "Central Mercedita." They supply forced draft for the Ward Single Pass Bagasse Furnaces which fire the Babcock & Wilcox Stirling Boilers of 3700 H.P.

Central Mercedita, situated in the rich Guines plain, in the municipality of Melena del Sur, turns out about 374 tons of sugar per day (2300 bags of 325 lbs. per bag). The Central was founded in 1850 by Don Jose Domingo Fresneda. It was acquired by its present owner, the Gomez Mena family (one of the oldest and best known families in Cuba) in 1925.

Wing Turbine Blowers as used in this plant are used in many a sugar central's boiler plant. They are simple and rugged in construction, quiet and dependable in operation. Their compact design has made them the favorite with boiler manufacturers and operators all over the world.

Write for a copy of Bulletin T-98.

Wing

L. J. Wing Mfg. Co.

54 Seventh Ave. New York 11, N. Y.

Factories: Newark, N. J. and Montreal, Canada

pounds a month!

C-E Steam Generator, Type VU

Consider these 6 Advantages:

1. **Symmetrical Design.** Any longitudinal section through the VU Unit is the same as any other. Each has the same amount of furnace volume, the same evaporative surface, the same superheating surface. Each functions under similarly uniform conditions — same mass flow of gases at practically the same temperatures at any given point. Thus each carries the same amount of water and produces the same amount of steam.

2. **Steam Quality.** All of the most active steam producing tubes enter a baffled area in the drum — see illustration — which discharges well above the waterline and uniformly across the full length of the drum. This arrangement reduces turbulence to a minimum and permits effective utilization of the entire steam release space. Dry steam and a stabilized water level are thus assured even under adverse conditions.

3. **Standardized Construction.** Painstaking refinement of detail is incorporated in each unit at a fraction of the original engineering cost. With standard parts and structural features, the merits of which are confirmed by experience, manufacturing and erection costs are materially reduced. First cost reflects the economy of standardized design and the buyer gains this benefit even before the VU Unit is placed in operation.

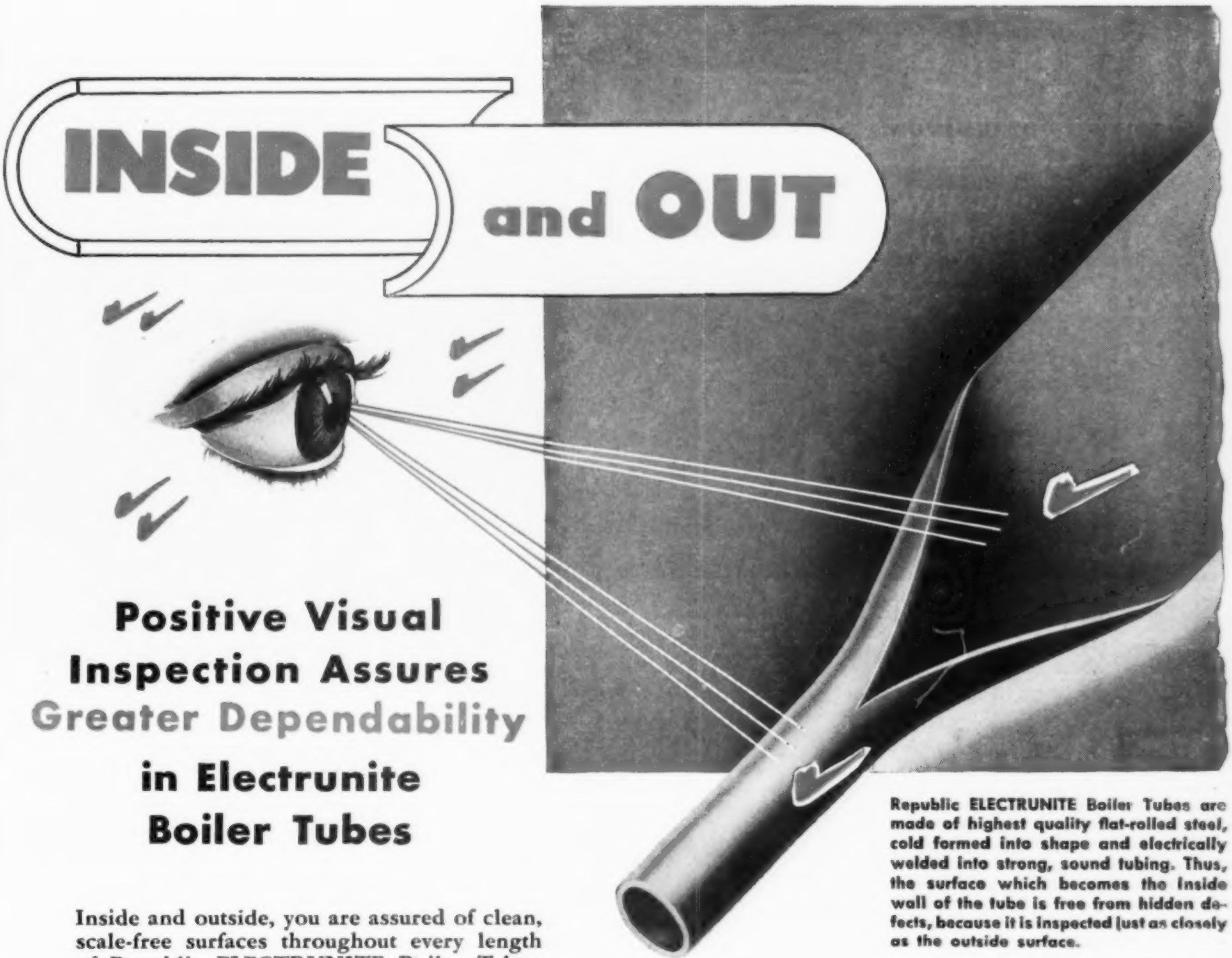
4. **Overhead Suspension.** Complete freedom of expansion in all directions is assured because all parts of the unit are suspended from the steel structure which provides the framework for the steel casing. This feature makes ample provision for the effects of temperature changes; it eliminates abnormal mechanical stresses on all pressure parts and explains to a large degree the freedom of the VU Unit from leaky joints.

5. **Adaptable in Application.** The VU Unit may be fired by pulverized coal, oil, gas or any combination of these fuels. It is likewise readily adaptable to firing by any type of stoker. These units are suitable for widely varying requirements of load, pressure and temperature. Inclusion of an interbank or intertube superheater, an air heater or economizer, is easily accomplished as conditions require.

6. **Steel Encased Setting.** The unit setting of shaped tile, refractory and 100% insulation are attractively finished by a permanent outer steel casing. This design, evolved from careful study and experiment, reduces to a minimum heat losses caused by radiation and air infiltration. It tends to eliminate hot spots and helps maintain a uniformly low surface temperature throughout the steel casing. Maintenance is negligible.

ENGINEERING

200 MADISON AVENUE, NEW YORK 16, N. Y.



Positive Visual Inspection Assures Greater Dependability in Electrunite Boiler Tubes

Republic ELECTRUNITE Boiler Tubes are made of highest quality flat-rolled steel, cold formed into shape and electrically welded into strong, sound tubing. Thus, the surface which becomes the inside wall of the tube is free from hidden defects, because it is inspected just as closely as the outside surface.

Inside and outside, you are assured of clean, scale-free surfaces throughout every length of Republic ELECTRUNITE Boiler Tubes.

Why? Because ELECTRUNITE Boiler Tubes are cold formed from flat-rolled steel, both sides of which are open to close visual inspection.

But that's not all! There are other reasons why it pays to use Republic ELECTRUNITE Boiler Tubes.

These *modern* boiler tubes speed up retubing. They are free from hard spots—are uniformly high in ductility—because they are full normalized throughout their entire length.

And because they are consistently uniform in wall thickness, diameter and roundness, ELECTRUNITE Boiler Tubes slide in freely, roller expand smoothly and bead over to tight, non-leaking joints in a hurry.

As an added safeguard of uniformly high quality, samples taken at regular intervals during production undergo a rigid testing routine—and every tube is subjected to a hydrostatic pressure well in excess of code requirements before it leaves the factory.

ELECTRUNITE dependability is proved by the fact that more than 150,000,000 feet have been installed in all types of steam generating and heat transfer equipment.

For more information about ELECTRUNITE Boiler Tubes and the Electric Resistance Weld Process by which they are made, write for your copy of our new brochure.

REPUBLIC STEEL CORPORATION
STEEL AND TUBES DIVISION • CLEVELAND 8, OHIO
Export Department: Chrysler Building, New York 17, N. Y.

Republic
ELECTRUNITE
Reg. U. S. Pat. Off.
BOILER, CONDENSER AND HEAT EXCHANGER TUBES

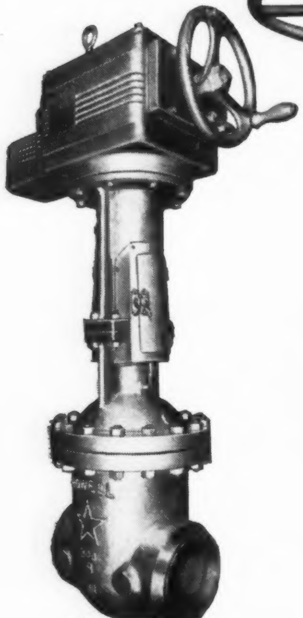
For assured performance, the valve *must* suit the service!

For certain services, Iron Valves are fully adequate. In others, Bronze Valves are especially suitable. And, in many installations, Steel Valves are definitely required. Moreover, the modern trend toward higher and higher pressures and temperatures in power installations has imposed many new demands for special flow control equipment. As always through 100 years of making valves for industry, Powell Engineers have met every challenge.

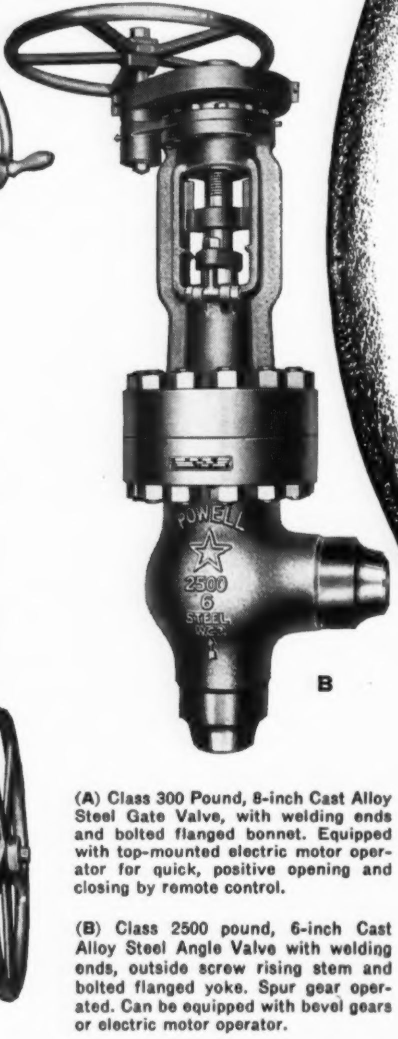
Today, in addition to complete lines of Bronze and Iron Valves of every required type and size and Cast Steel Valves of all types in pressure classes from 150 to 2500 pounds, Powell can furnish valves designed to meet special requirements of the modern power plant. A few are shown here.

In writing for catalogs, kindly state your requirements. Powell Engineers will be glad to help you select the correct valves to suit the service.

The Wm. Powell Co., Cincinnati 22, Ohio



A



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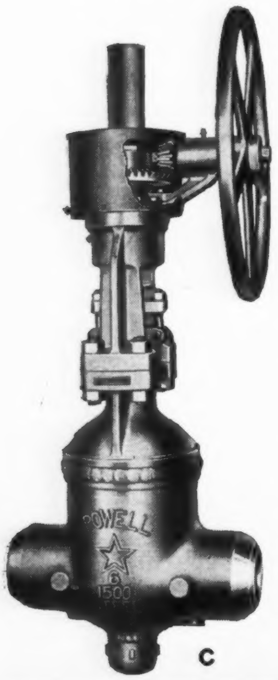

C

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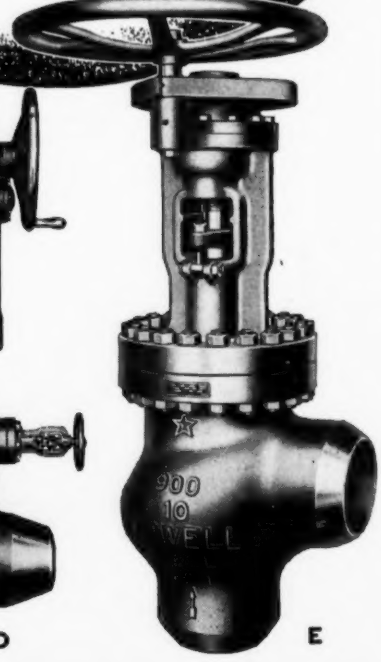


E

(A) Class 300 Pound, 8-inch Cast Alloy Steel Gate Valve, with welding ends and bolted flanged bonnet. Equipped with top-mounted electric motor operator for quick, positive opening and closing by remote control.

(B) Class 2500 pound, 6-inch Cast Alloy Steel Angle Valve with welding ends, outside screw rising stem and bolted flanged yoke. Spur gear operated. Can be equipped with bevel gears or electric motor operator.

(C) Class 1500 pound, 6-inch Cast Alloy Steel Gate Valve with welding ends and welded bonnet. Bevel gear operated.

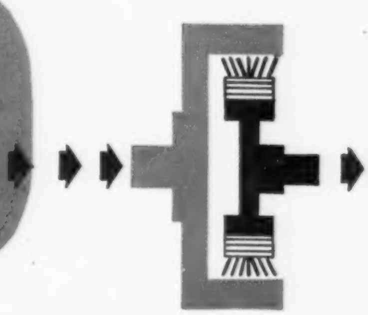
(D) Class 1500 pound, 8-inch Cast Alloy Steel Gate Valve with welding ends, welded bonnet and special by-pass. Top-mounted electric motor operator provides quick, positive opening and closing.

(E) Class 900 pound, 10-inch Cast Alloy Steel Non-return Angle Valve, with welding ends. Spur gear operated. Powell Non-return valves are available also with bevel gear, toggle or motor operation.

POWELL VALVES

THE MODERN

Answer



To These Drive Problems... *Calling for Adjustable Speed Control*

Today's answer in getting economical, adjustable-speed control for boiler draft fans, centrifugal pumps and centrifugal compressors is the E-M Adjustable-Speed *Magnetic Drive.*

The Magnetic Drive is a simple, compact electro-magnetic torque transmitter. It is installed between a squirrel-cage or synchronous motor and the driven equipment, and operates in combination with an electronic controller to maintain selected speed regardless of changes in load. The Magnetic Drive requires no fluids; is simple, rugged and clean; provides precise, micro-step speed control over a wide range with immediate response to load requirements.

Boiler draft fans are the outstanding application for Magnetic Drives, but the inherent features of the unit are also highly advantageous on all applications characterized by a load torque which drops off rapidly with reduction in speed, such as centrifugal pumps, centrifugal compressors and blowers.

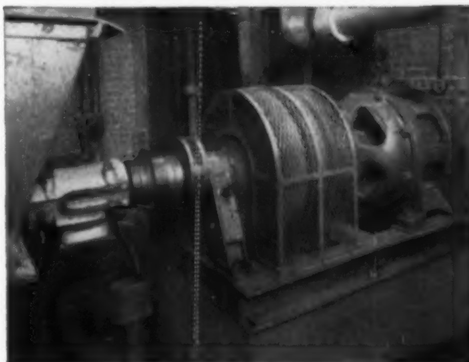
Write now for Publication No. 183, describing E-M Magnetic Drive construction, operation and advantages.

ELECTRIC MACHINERY MFG. COMPANY
MINNEAPOLIS 13, MINNESOTA

E-M

MAGNETIC DRIVES

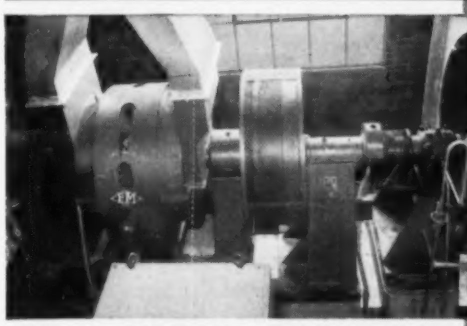
PRECISE, WIDE-RANGE, QUICK-RESPONSE SPEED CONTROL A2034



Answer 1

INDUCED DRAFT FANS

Wide-range, precise boiler draft control on an induced draft fan at a New Jersey paperboard company was provided when this 100 hp, 870/87 rpm, E-M Magnetic Drive unit replaced a slip-ring induction motor previously used.



Answer 2

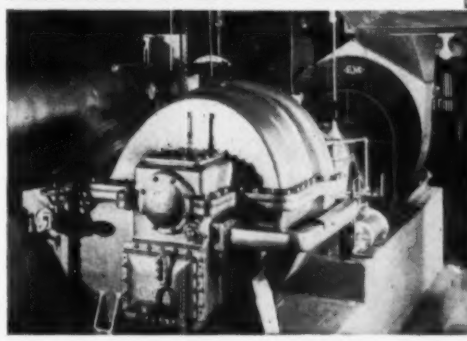
FORCED DRAFT FANS

Quick-response, adjustable speed control of forced draft fan at an Ohio power plant is provided by this 322 hp, 1145/280 rpm E-M Synchronous Motor-Magnetic Drive set. Induced draft fan also uses an E-M Magnetic Drive.

Answer 3

CENTRIFUGAL PUMPS

Two 40 hp, 1707/1056 rpm, E-M Magnetic Drives in a Wisconsin paper mill drive black liquor centrifugal pumps feeding boilers. Magnetic Drive is a compact unit installed between motor and pump to control fluid delivery rate.



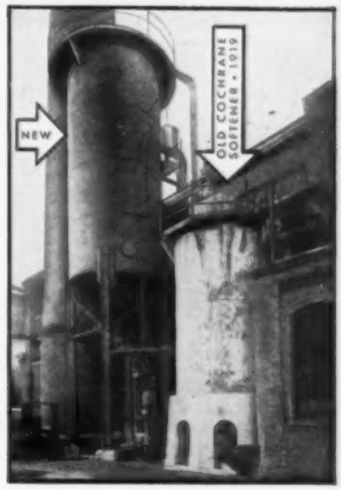
Answer 4

CENTRIFUGAL COMPRESSORS

Close-regulated, adjustable speed to suit refrigeration requirements for air conditioning in a Florida mercantile building is provided on this centrifugal compressor by an E-M 350 hp, 1150/840 rpm Magnetic Drive.

Above: Cochrane Flow Meter Panel for Automatic Control of Chemical Feed.

HISTORY (and Cochrane Water Conditioning Equipment) REPEATS

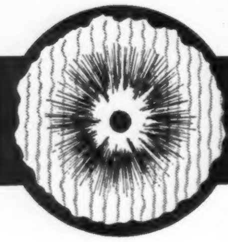


COCHRANE Water Conditioning Equipment does its work so thoroughly, so efficiently and with so little extra upkeep costs that "repeat" orders are the rule rather than the exception. The Deaerating Hot Process Softener shown in these photographs was ordered to replace the old Cochrane Hot Process Softener shown alongside it. This older piece of equipment is still functioning, but was not able to handle the increased load. At last reports it was destined to be shifted to another job. Write for details of this installation and facts about Cochrane Hot Process Water Softeners. Cochrane Corporation 3109 N. 17th St., Philadelphia 32, Pa.

Left: Upper part of Softener showing Deaerator Mechanism and Cochrane Multiport Relief Valve.

COCHRANE

ONE *recognized standard*



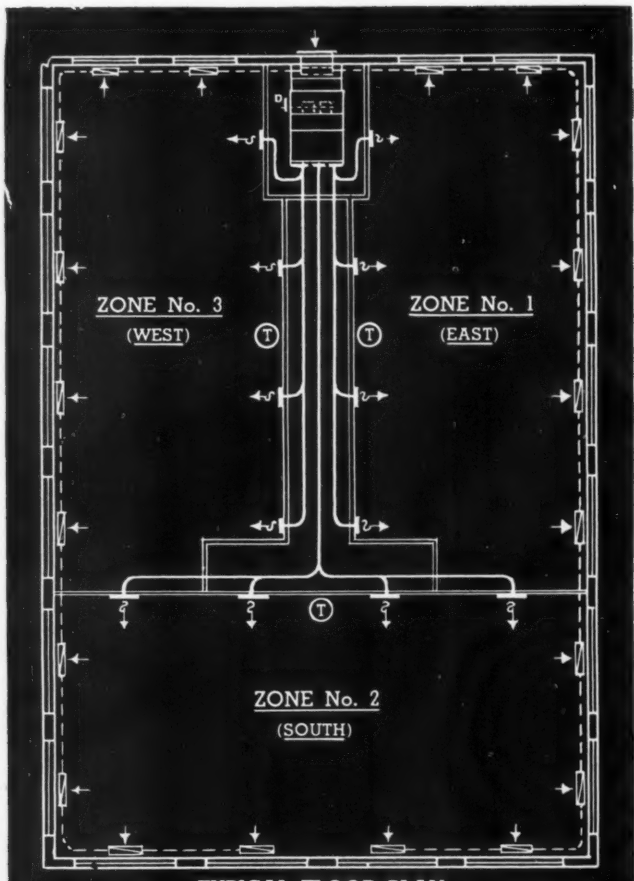
THE COTTRELL PROCESS OF ELECTRICAL PRECIPITATION

FOR GAS CLEANING, smoke abatement and removal of dust, fume, tar and other suspended matter from gas, there has been one universally accepted process for more than thirty years. In answer to your special problem, a Cottrell installation incorporating this rich experience in research, development and worldwide operation means the complete fulfillment of your requirements.

RESEARCH CORPORATION

NEW YORK 17: 405 LEXINGTON AVENUE
CHICAGO 3: 122 SO. MICHIGAN AVENUE

Zone Control using CLARAGE "Blow-Thru" Multitherms



TYPICAL FLOOR PLAN

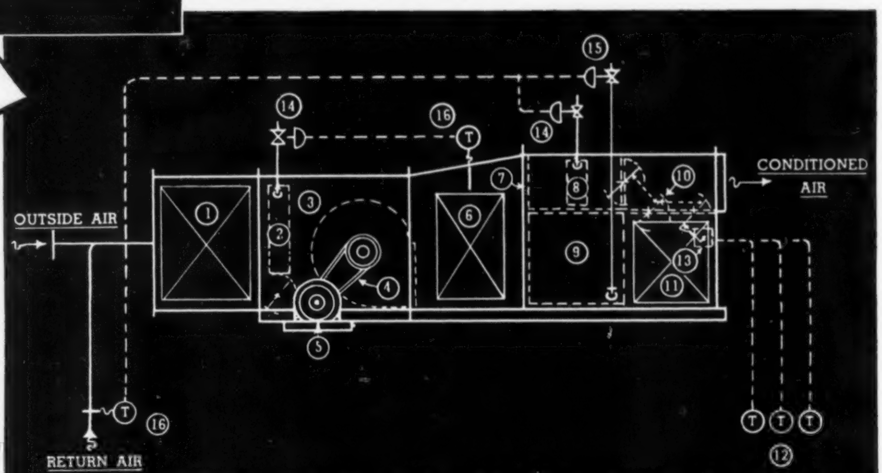
Now one Clarage "Blow-Thru" Multitherm Unit can be used to air condition various parts of your building exactly as requirements warrant. A typical 3-zone installation is shown at left. Unit can be arranged to serve from two to six zones — an exclusive Clarage development.

ZONE CONTROL compensates for the difference in solar radiation on different parts of a building during different periods of the day. It also takes into account variations in exposure, wind velocity, construction, and internal heat loads.

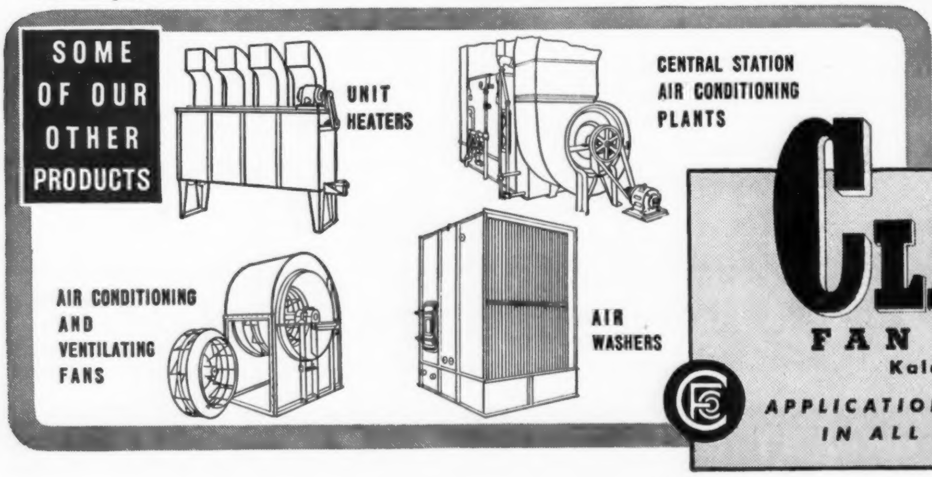
Thus winter and summer, if desired, you can maintain various temperatures in various parts of your building. Each zone is automatically controlled independently — yet only one conditioning unit necessary!

EQUIPMENT ARRANGEMENT

1. Filter Section
2. Tempering Coil with Steam Distributing Tubes
3. Fan Section
4. V-Belt Drive
5. Motor
6. Fan Discharge Section with Access Door
7. Distributing Plate
8. Reheat Coil with Steam Distributing Tubes
9. Cooling Coil
10. Zone Double Mixing Dampers (3 sets)
11. Access Door
12. Zone Room Thermostats
13. Zone Damper Motors
14. Steam Valve
15. Cold Water or Refrigerant Valve
16. Temperature Controller



TYPICAL "BLOW-THRU" MULTITHERM AND BASIC CONTROL



Clarage ZONE CONTROL air conditioning is adaptable to practically any type of building — industrial, commercial, etc. Write for further data.

CLARAGE FAN COMPANY
Kalamazoo, Michigan

APPLICATION ENGINEERING OFFICES IN ALL PRINCIPAL CITIES

"I'll lay you a buck it's the same outfit!"

"Go on!" Sam retorted. "The heat's got you, Bill. Maybe you oughta put the insulation on your head."

"My head's all right," Bill declared. "And I guess I know who's installing the magnesia on our own steam lines."

"Maybe you think you know. All I say is, it can't be the same Armstrong. The company I'm talking about makes corkboard, like my nephew used in his new locker plant."

"That's just what I'm saying. Armstrong is an insulation outfit. They handle cold jobs, and heat jobs, too. I've talked to their foremen. Their trucks drive up to our plant. We've got a contract with them. What more do you want?"

"Pipe down, you birds," cut in the man behind them. "Don't you know there's a ball game going on here?"

"Keep your shirt on, fella," Sam shot back. "This is important."

"Look," says Bill. "Let's settle it this way. Monday morning, you phone the Armstrong Cork Company and ask them. If they don't sell heat insulation, I'll buy both of us grandstand seats next Saturday. And if they *do* . . ."

• • •

Sam had to buy the baseball tickets, of course. For Armstrong does furnish heat insulation, as well as low-temperature insulation. Some folks know us best for one, some for the other. Many use our services on both.

In the low-temperature field, Armstrong supplies three kinds of insulation, to hold temperatures all the way down to 300° below zero. For heat applications, we offer a complete line of insulations for steam lines and equipment. And there are five types of Armstrong's Insulating Brick to withstand temperatures all the way from 1600° to 2600°F.

We not only sell the materials, but we'll also be glad to help with your engineering problems. And we can supply skilled workmen to install your complete job. Materials, engineering, and workmanship together make up Armstrong's Contract Service. If you'd like the complete story, send for our new folder: "Armstrong's Insulation Contract Service." We think you'll find it interesting. Just drop a card to Armstrong Cork Co., Building Materials Div., 9306 Concord St., Lancaster, Penna.

ARMSTRONG'S INDUSTRIAL INSULATION

Complete Contract Service For All Temperatures

From 300° Below Zero — To 2600° Fahrenheit

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